United States Environmental Protection Agency

Overview of Geophysics for Environmental Site Characterization and Monitoring

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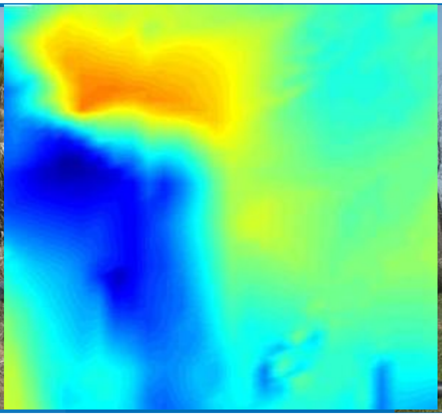
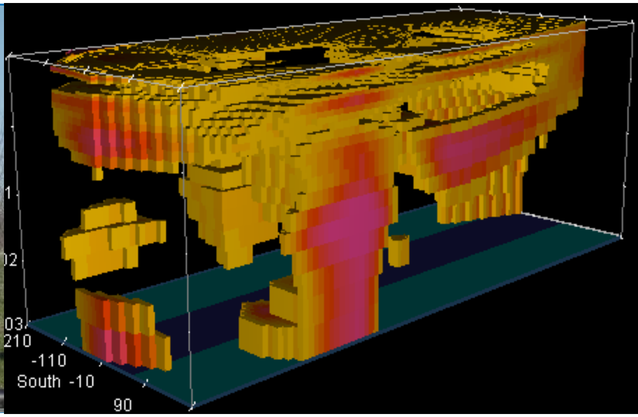
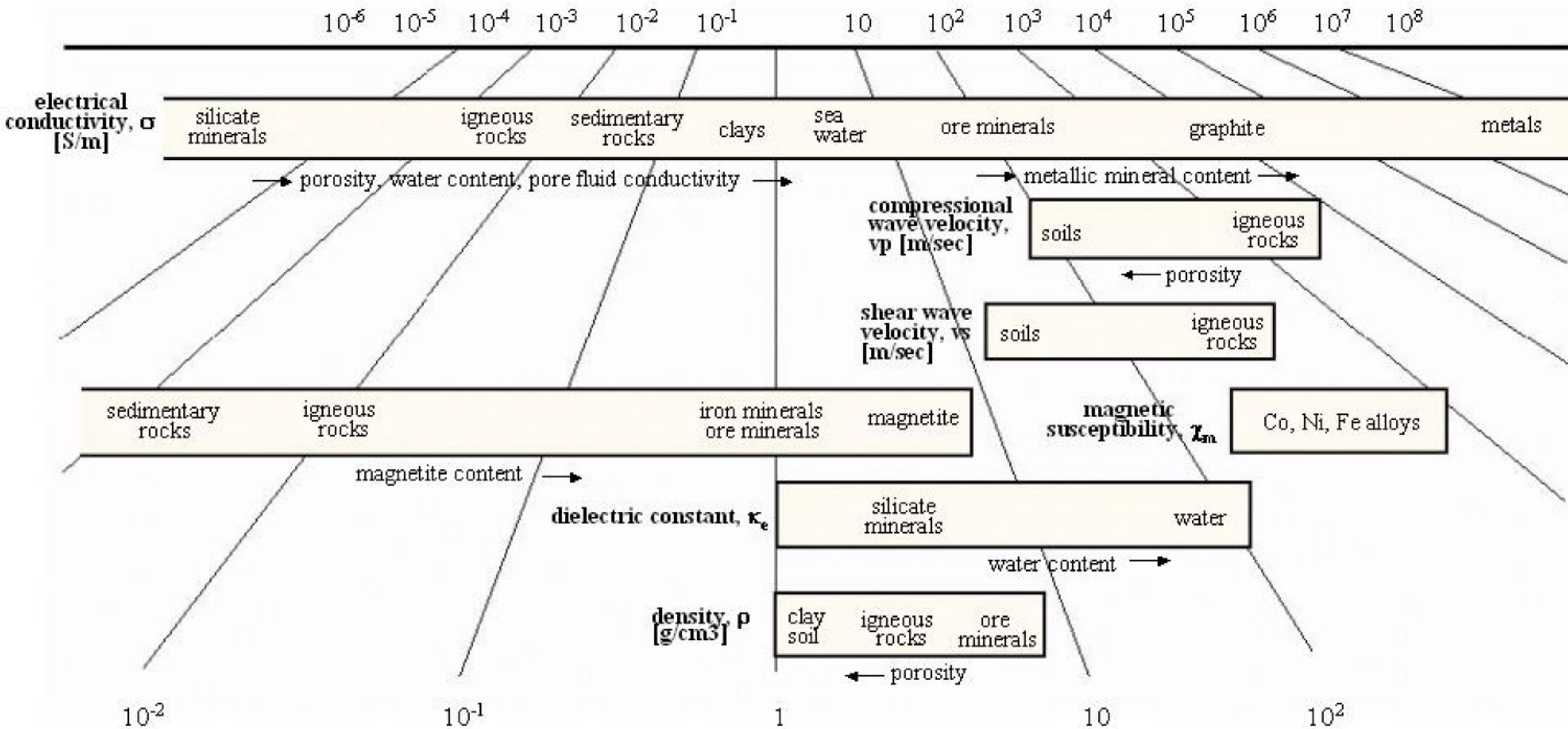
Office of Research and Development





Geophysical Properties



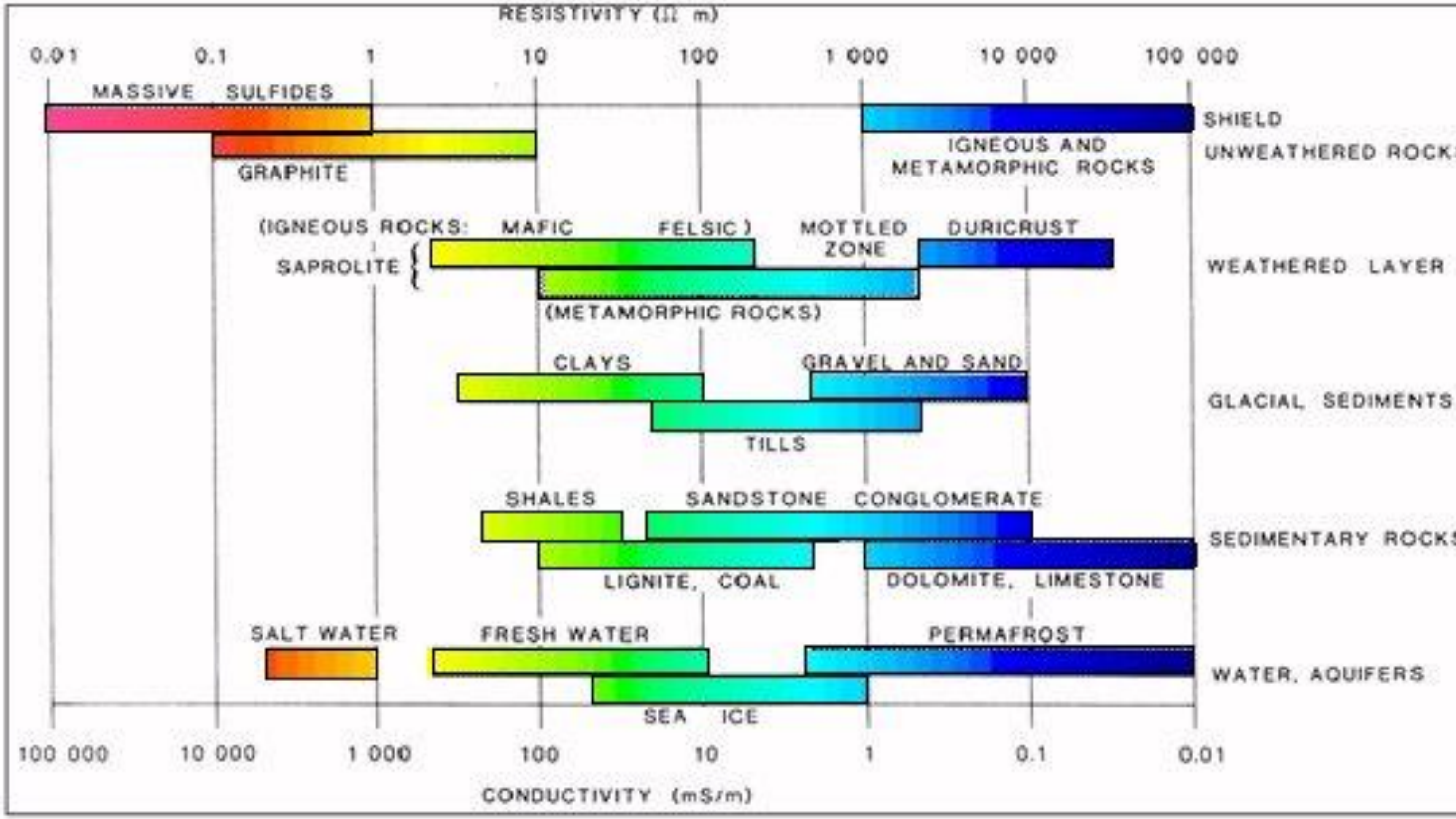
From http://appliedgeophysics.berkeley.edu:7057/intro/figures/fig_prop.jpg

Electrical Conductivity

Units:

S/m
mS/cm

Ωm



From http://www.eos.ubc.ca/ubcgif/ **(adapted from Palacky, 1987)**

Conductivity is a function of porosity, permeability, saturation, fluid conductivity, clay content, temperature

Seismic Wave Velocity

Material	v_p (m/s)
Soil	250-600
Weathered Layer	300-900
Alluvium	500-2000
Clay	1100-2500
Air	331.5
Water	1400-1600
Sandstone and Shale	2000-4500
Coal	1800-3400
Limestone	2000-6000
Igneous	5000-6400

Values summarized from various texts and online sources

Variability caused by differences in:

Saturation
Consolidation
Weathering
Fracturing

v_p is the P-Wave (compressional) velocity, this is always greater than the S-Wave (shear) velocity, v_s. The ratio of v_p/v_s is diagnostic of rock type.

Magnetic Susceptibility

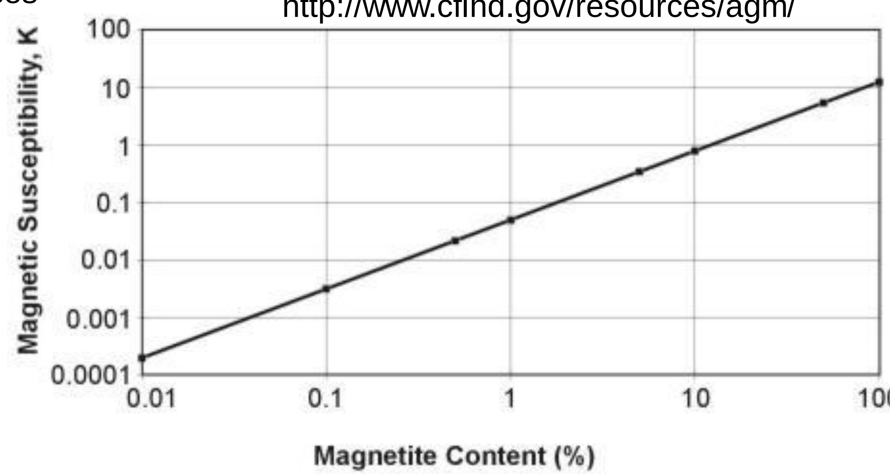
Rock or Mineral Type	Susceptibility X 1000 (SI units)
Sedimentary rocks	0.1-0.9
Metamorphic rocks	0.7-6
Igneous rocks	2.5-160
Magnetite	1200-19200
Ilmenite	300-3500
Pyrrhotite	1-6000

Values summarized from various texts and online sources

Dimensionless quantity describing the ability of a material to be magnetized

Depends primarily on magnetite content

http://www.cflhd.gov/resources/agm/



Dielectric Constant

Measure of polarization (electronic, ionic, or molecular) resulting from an applied electric field.

Diagnostic of the amount of water present

Material	Dielectric Constant
Water	80.36
Ice	3-4.3
Sandstone (dry to moist)	4.7-12
Packed sand (dry to moist)	2.9-105
Soil (dry to moist)	3.9-29.4
Clay (dry to moist)	7-43

Values summarized from various texts and online sources

Varies inversely with frequency

Density

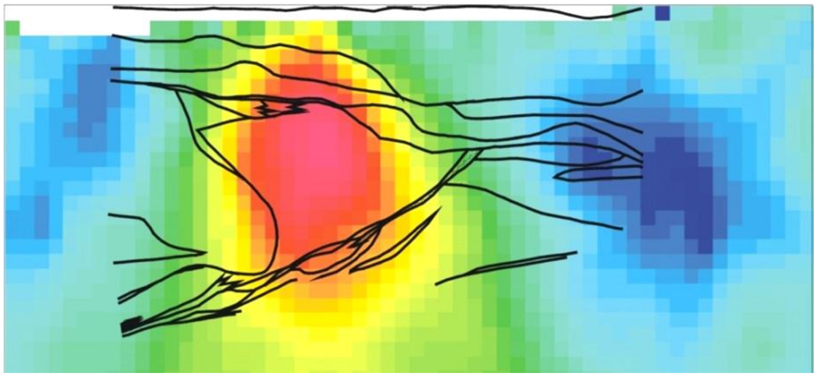
- Density generally increases with depth and time of burial
- Igneous and metamorphic rocks are generally more dense than sedimentary rocks
- Wider variability in sedimentary rocks due to variations in porosity

Material	Density (g/cm^3)
Water (fresh)	1.0
Soil / Overburden	1.2-2.4
Sandstone	1.6-2.7
Shale	1.7-3.2
Limestone	1.9-2.9
Granite	2.67-2.79
Basalt	2.7-3.3
Metamorphic	2.4-3.1

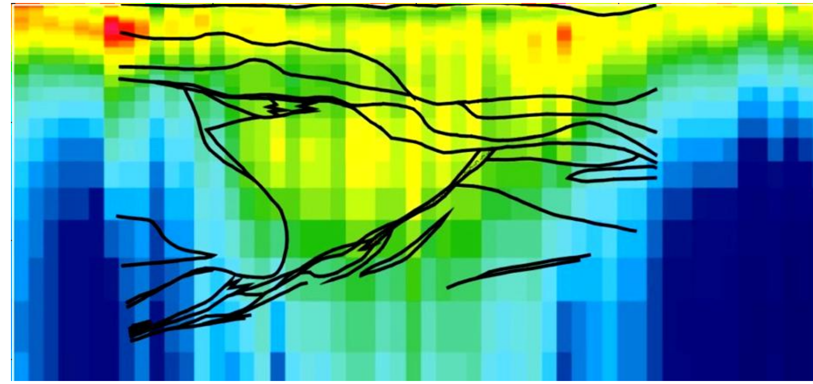
Values summarized from various texts and online sources

Global average for crustal rocks is 2.67 g/cm^3 (2670 kg/m^3)

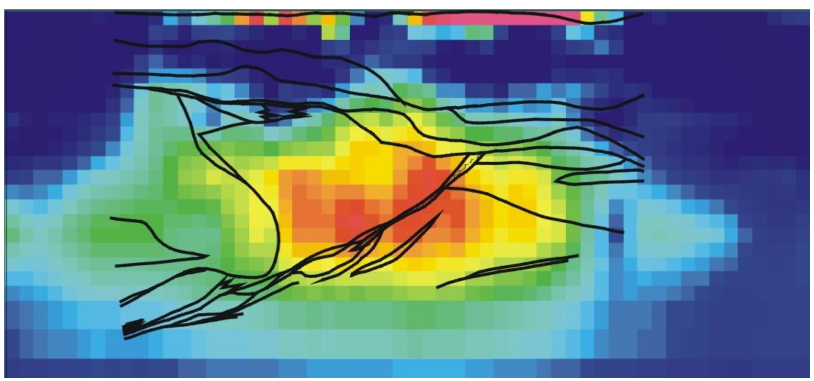
Which is Best to Use?



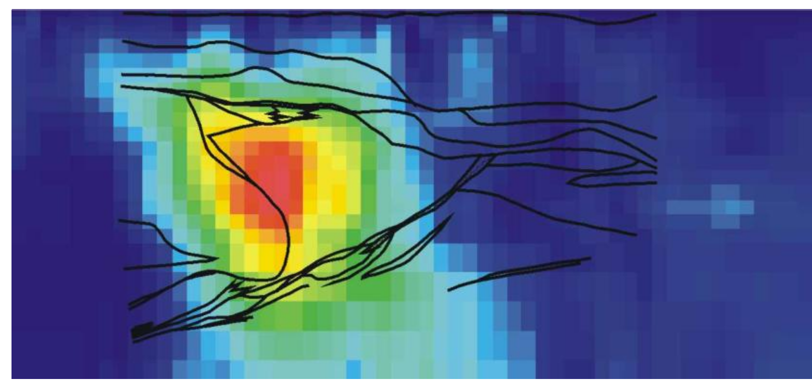
density-contrast



conductivity



chargeability

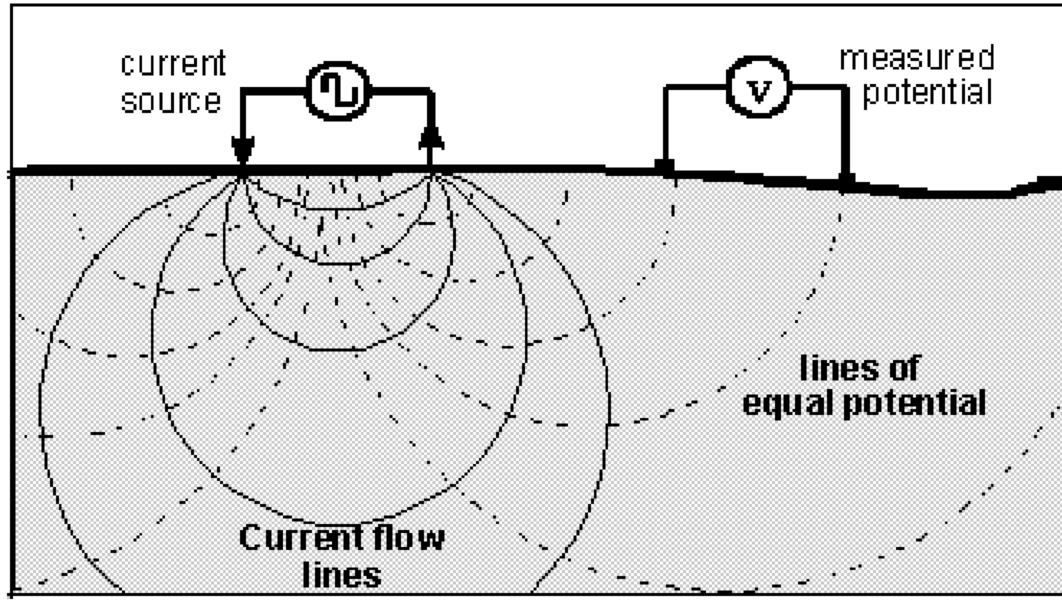


magnetic susceptibility

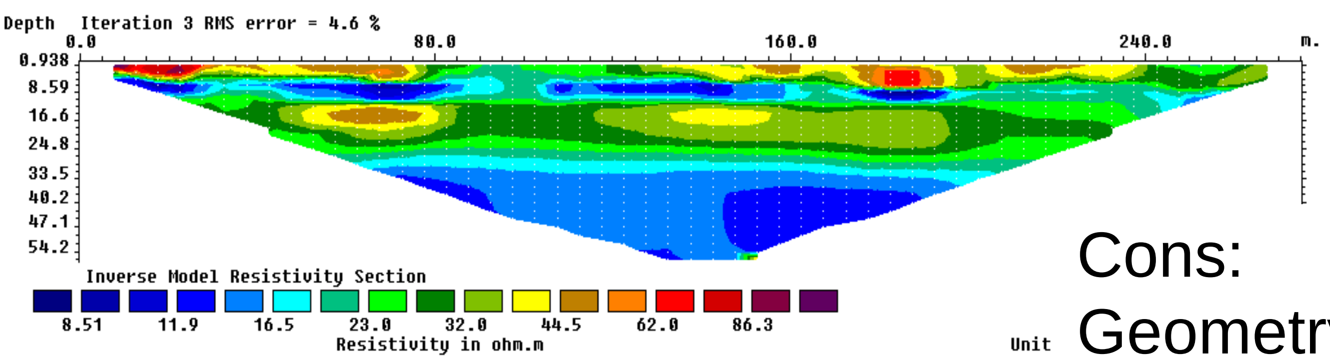
Good website for method selection at:

http://www.enviroscan.com/html/technique_selection.html

DC Resistivity

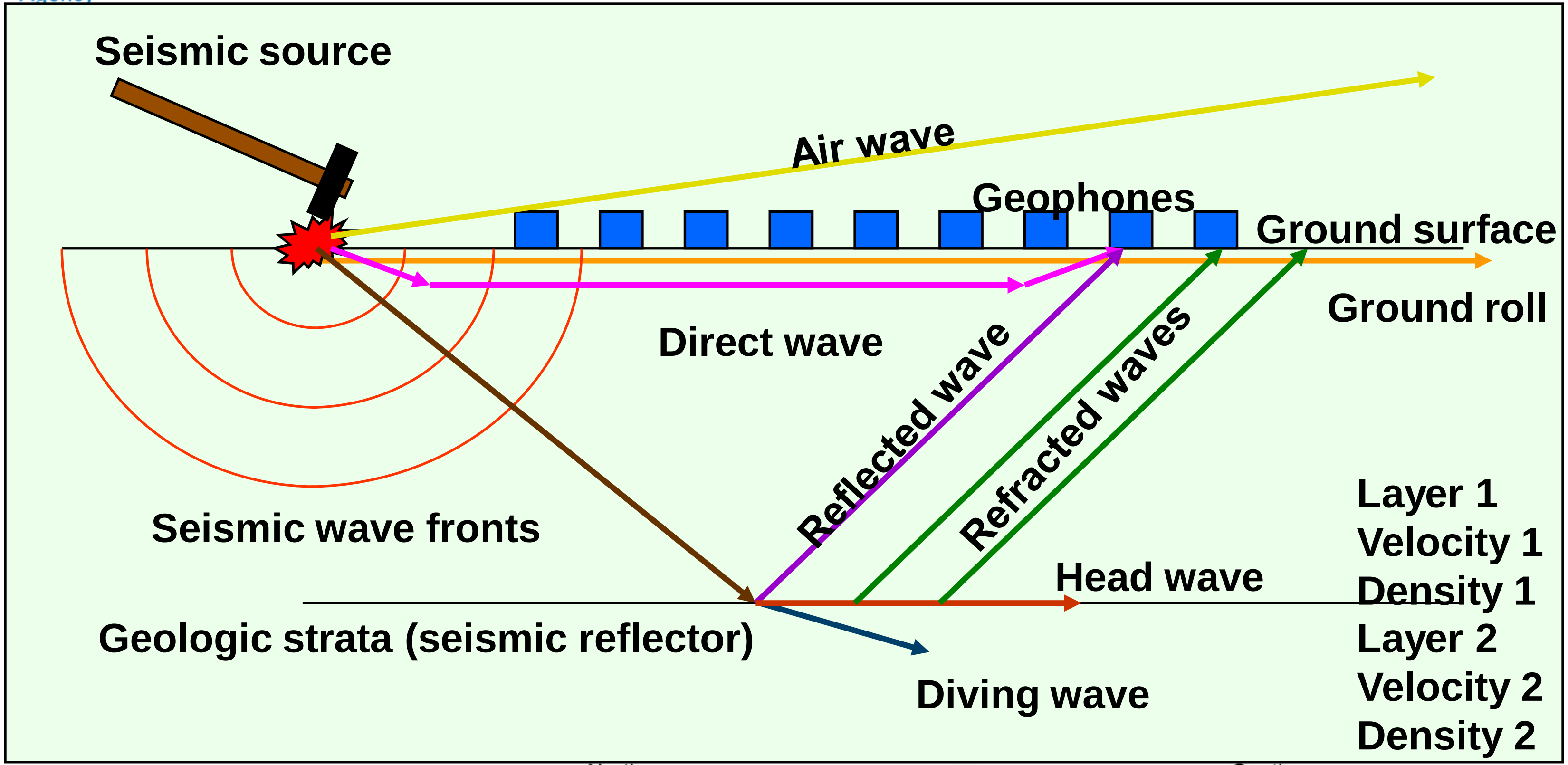


Pros:
Sensitive to water
Less interference vs. EM

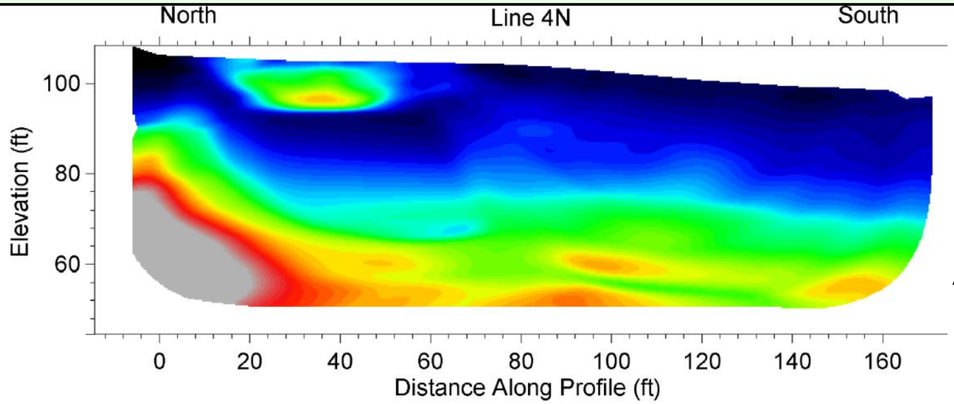


Cons:
Geometry dependent
Challenging in arid regions

Seismic Refraction

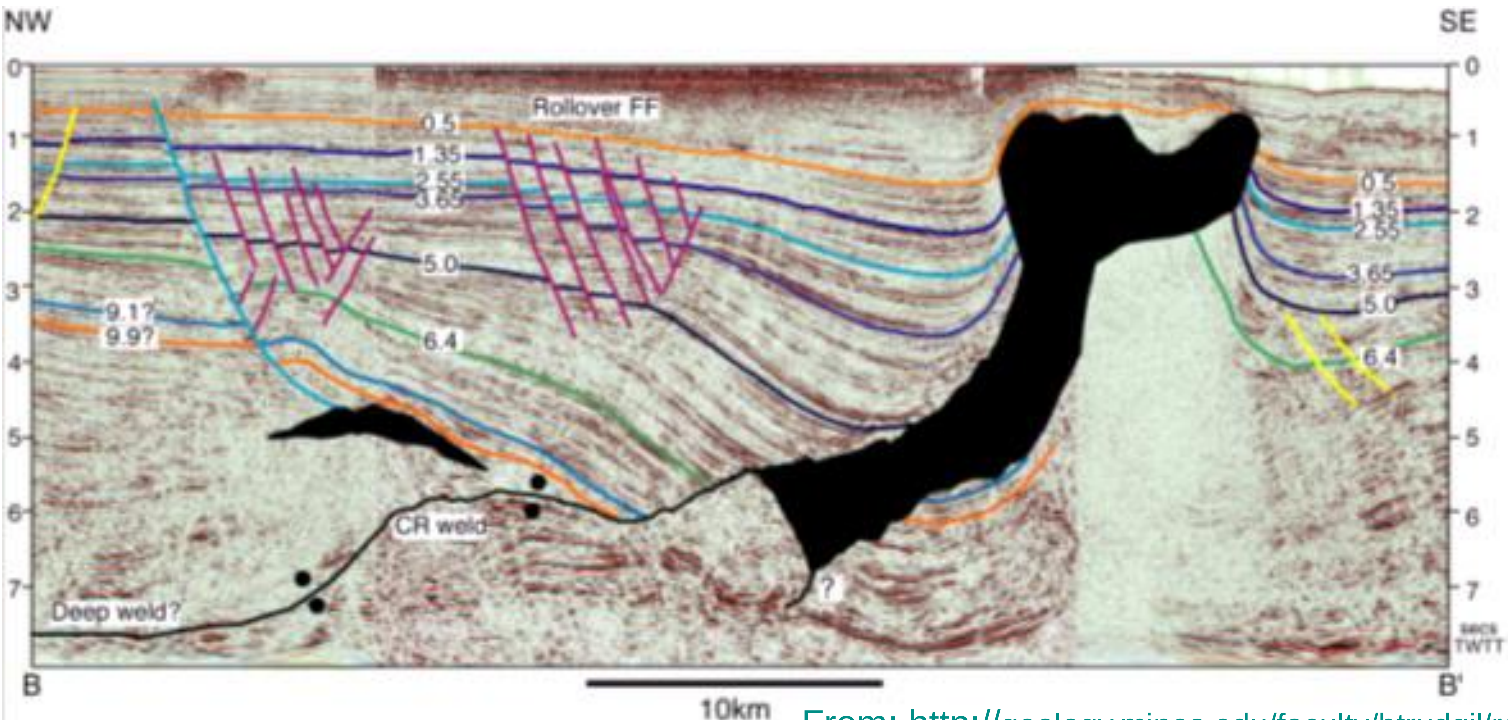


Pros:
Good resolution
Few interferences



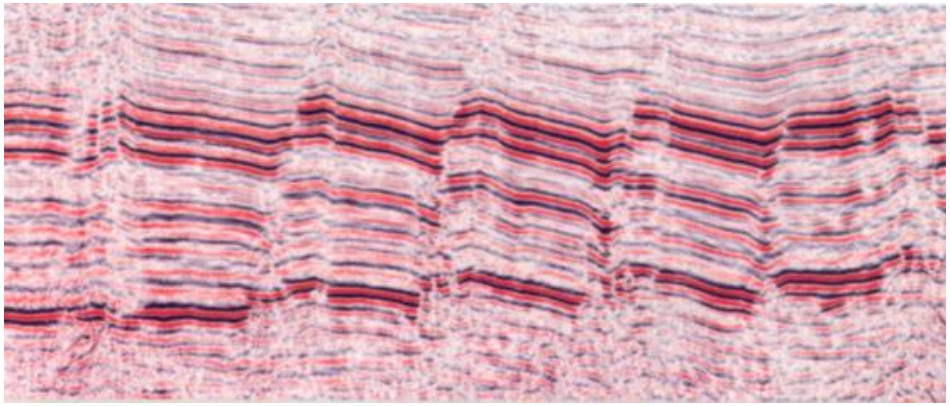
Cons:
Logistics
Assumptions

Seismic Reflection



From: http://geology.mines.edu/faculty/btrudgil/research.html

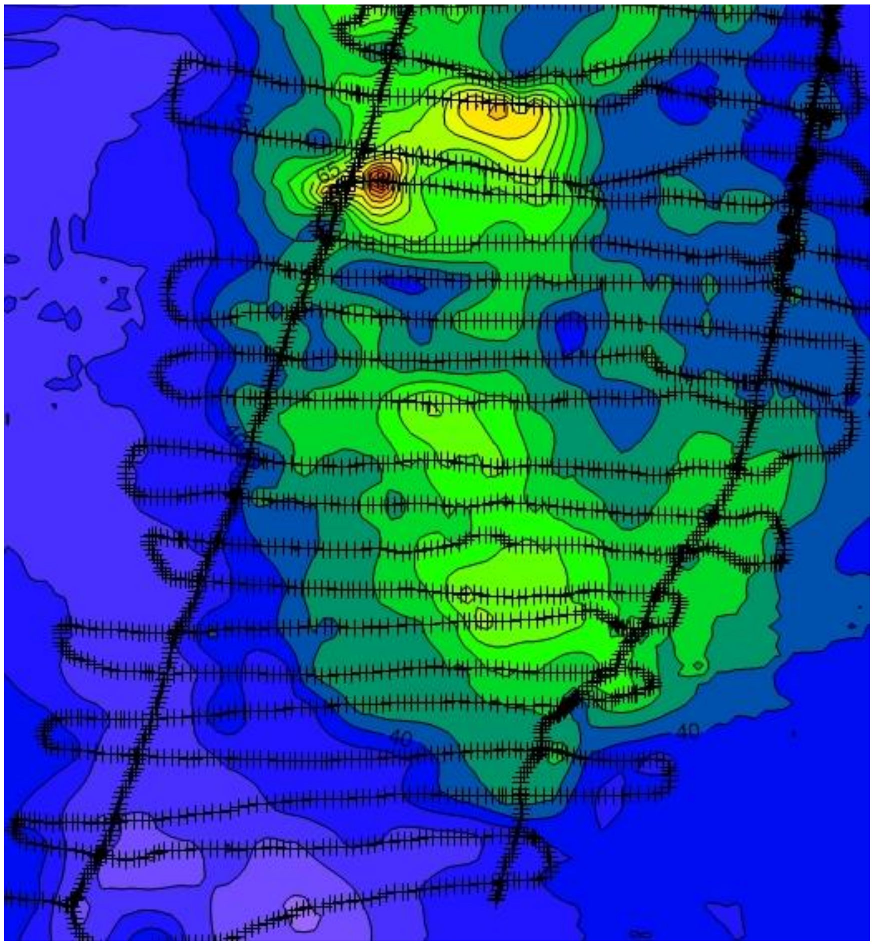
Pros:
High resolution
Scale & depth



Con:
Cost
Permits/Access

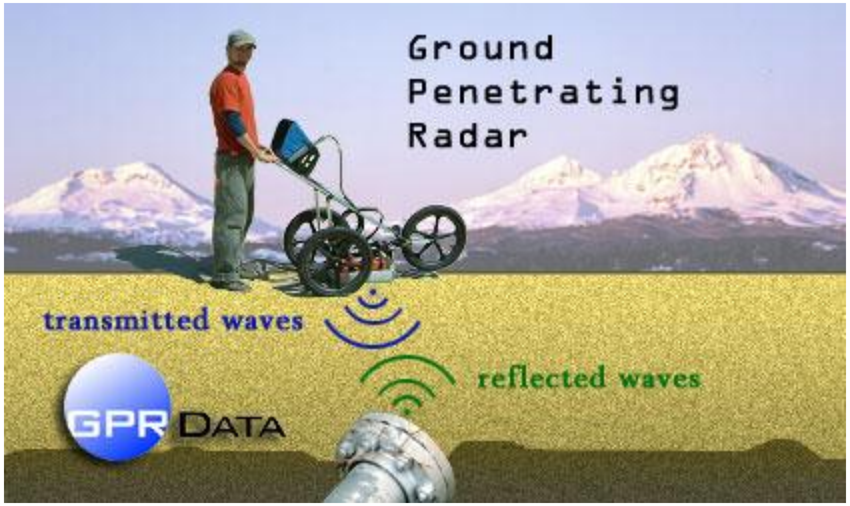
Frequency Domain EM

Pros:
Fast
Good recon tool



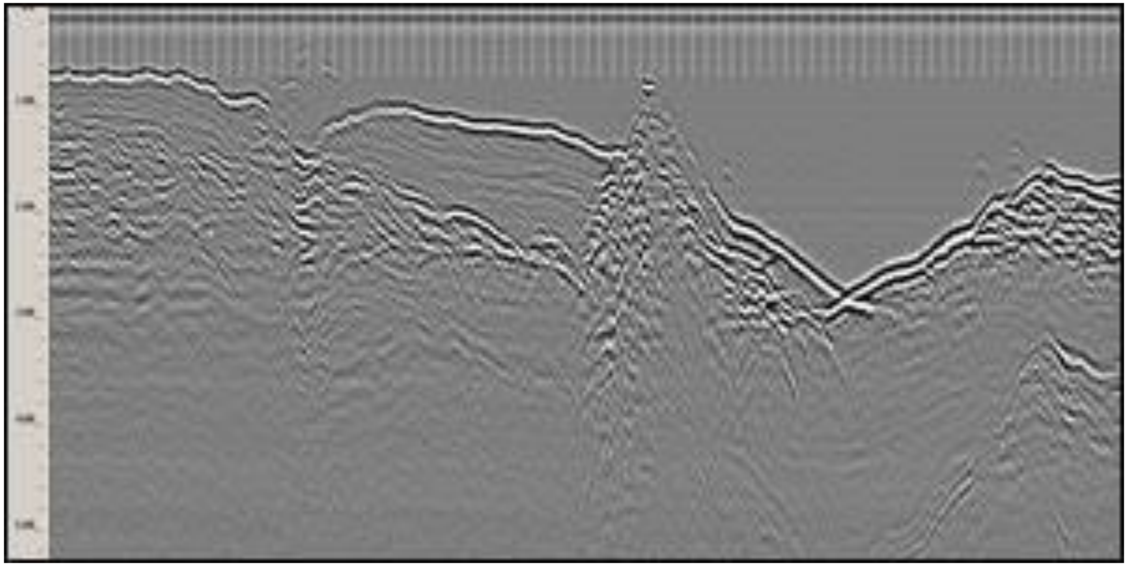
Cons:
Limited depth
Interferences

Ground Penetrating Radar

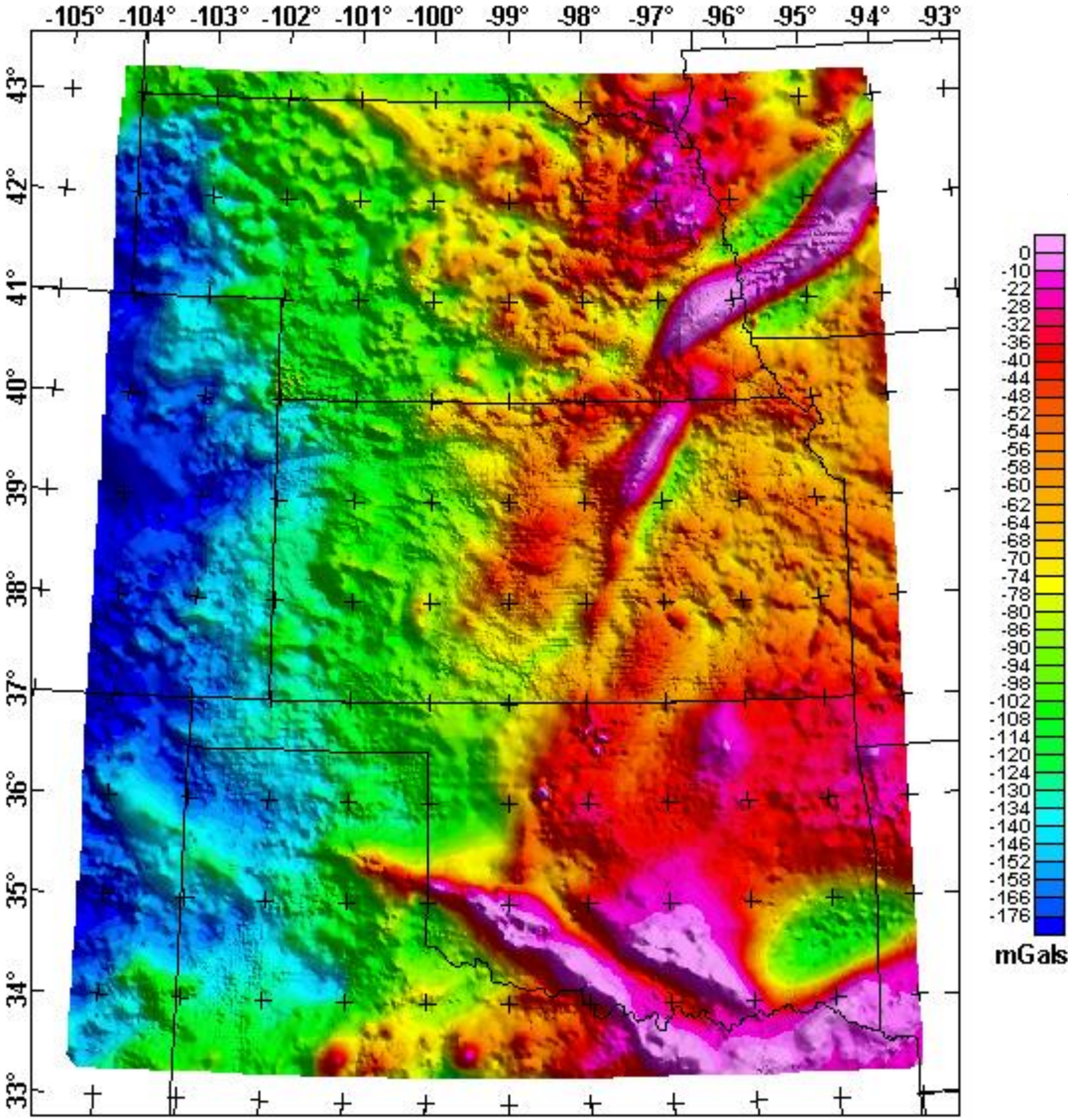


Pros:
High resolution
Fast

Con:
Limited depth



Gravity



Pros:

Depth of investigation

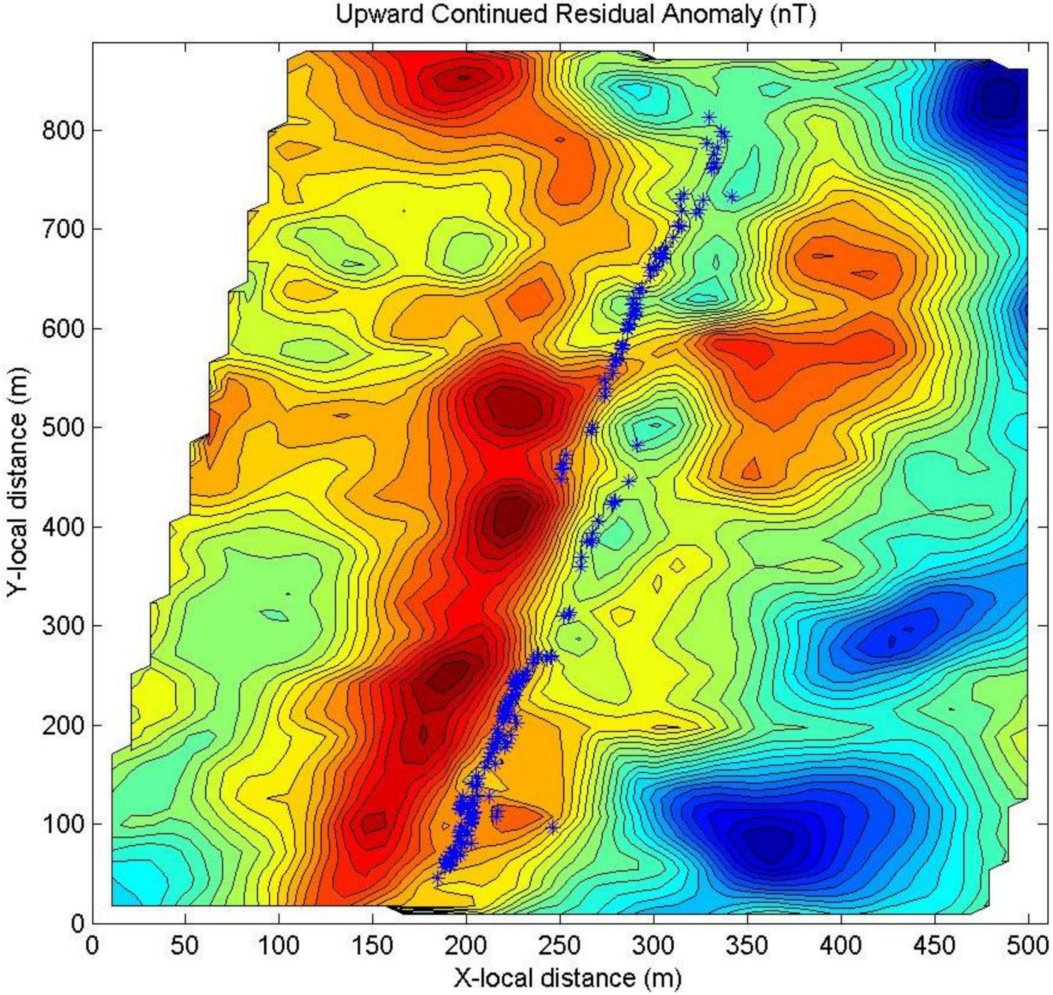
Scale

Cons:

Slow data acquisition

Interpretation

Magnetics

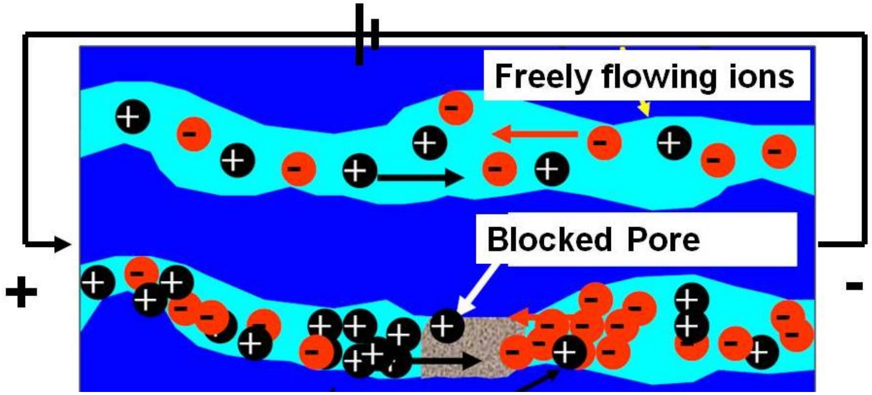


Pros: Relatively fast
Direct interpretation

Cons:
Modeling often complex
Interferences

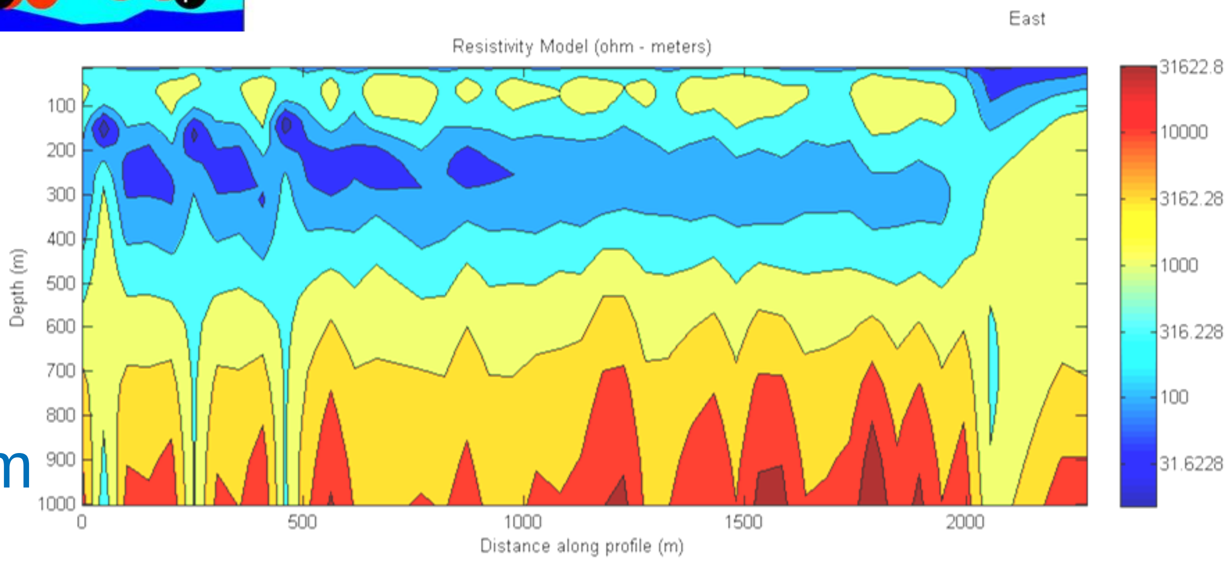
Other Methods

Electrical self potential – provides information about groundwater flow, chemical and temperature gradients



Induced polarization – Measures chargeability, related to porosity structure, mineral grain size

Controlled source electromagnetics – Surface techniques used to measure electrical conductivity to depths of several km

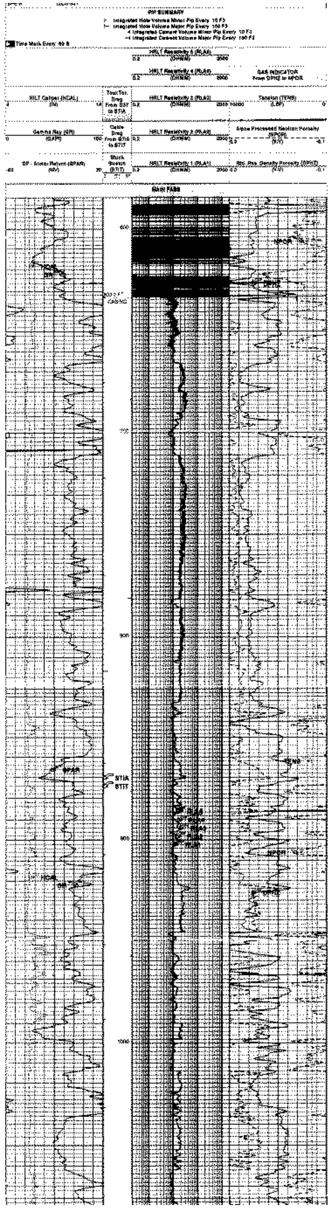


Borehole Logging

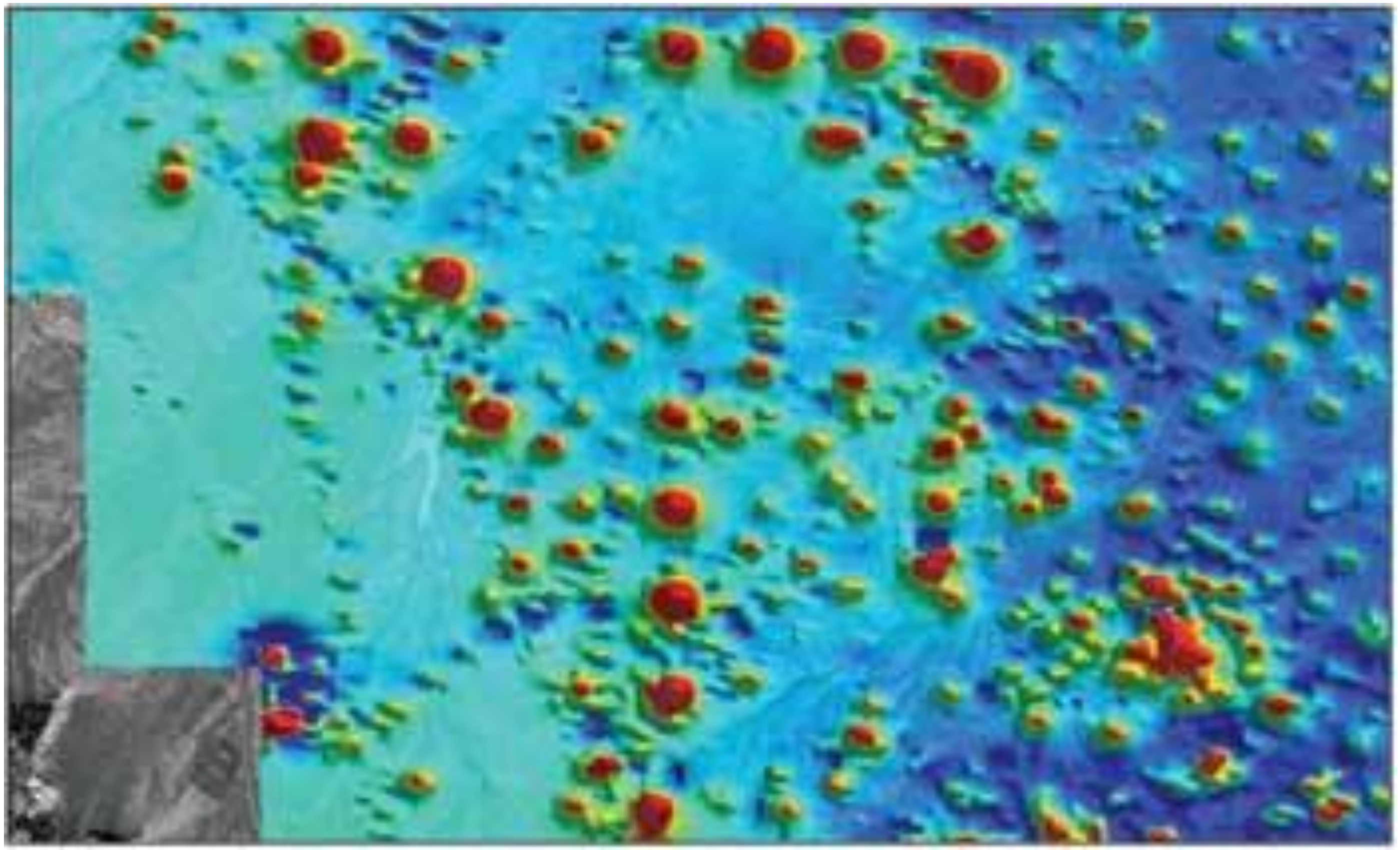
Spontaneous Potential
Magnetic Susceptibility
Natural Gamma
Caliper
Resistivity
Induction
Sonic
Density
Video
Temperature
Mud log
Cement Bond Log
Others…

Useful for determining:
Geological units
Water bearing zones
Screen settings
Pump depth
Packer locations

Also, can use some of the previously discussed methods in boreholes.



Airborne Geophysics



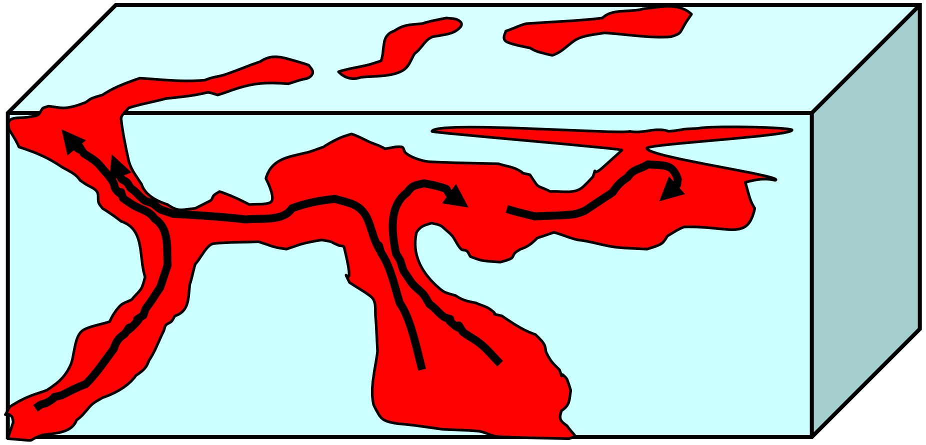
http://www.worldoil.com/Article.aspx?id=40370

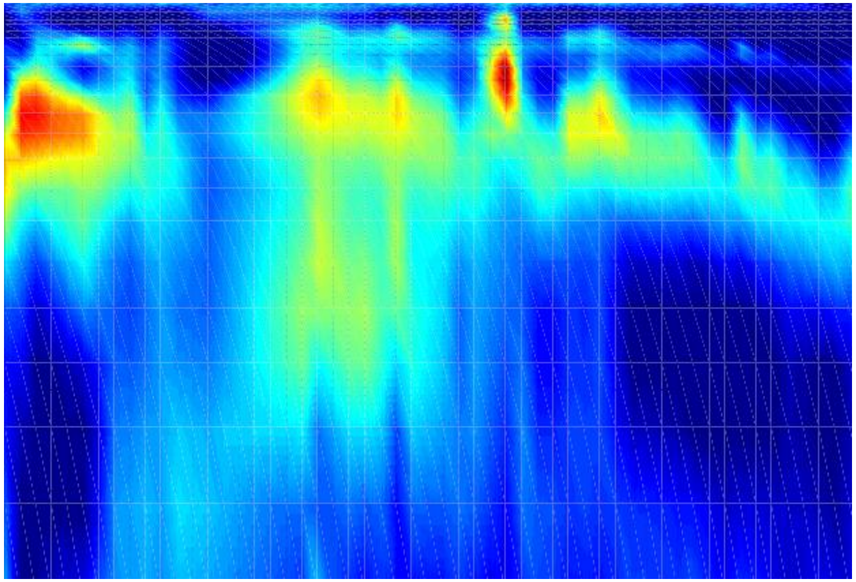
Generally lower resolution but covers large areas quickly
Often used as a reconnaissance tool to identify areas for detailed ground-based investigation

Electromagnetics Example

Goal – Characterize a geothermal resource and identify possible drilling targets

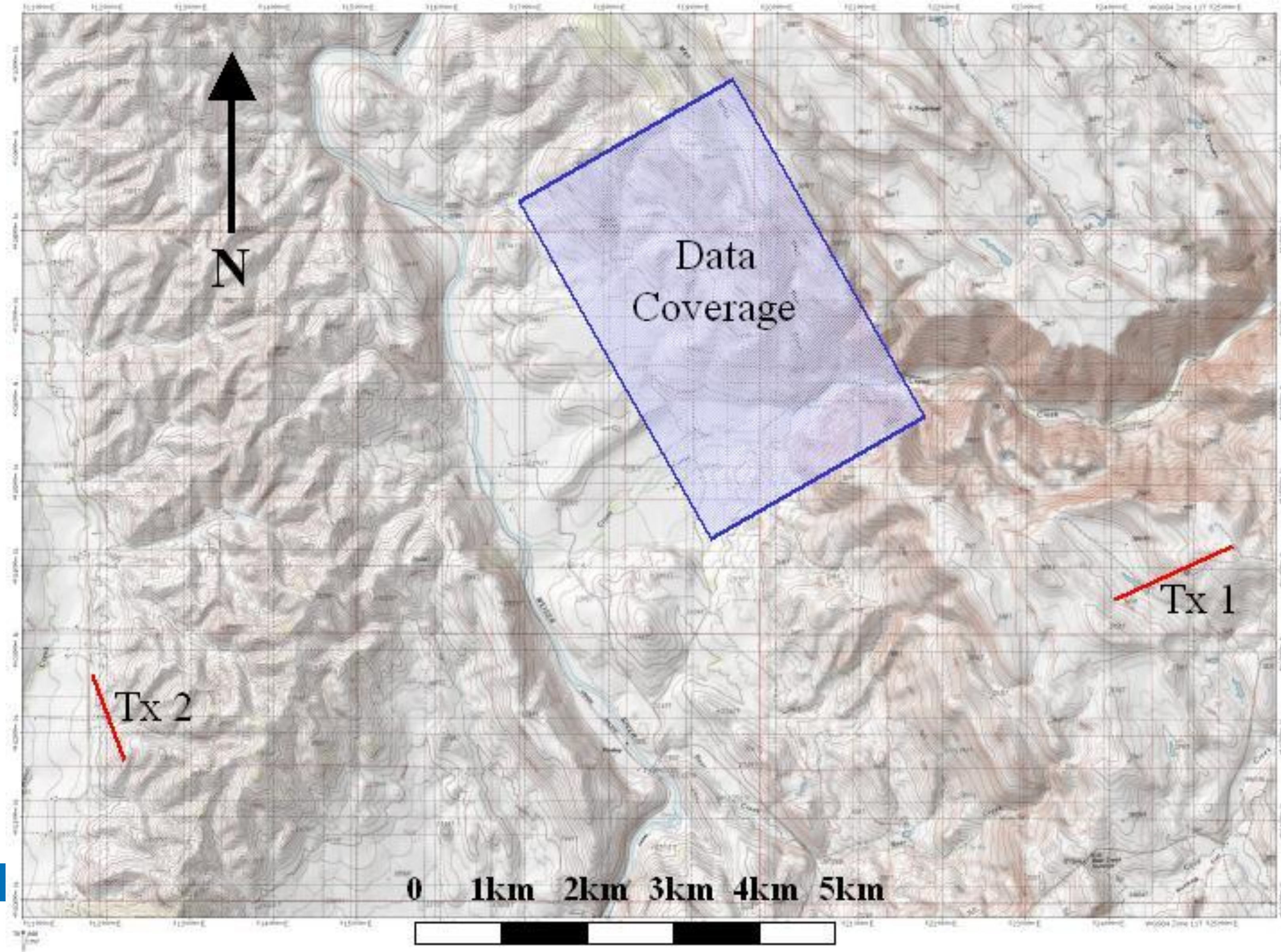
Method – Controlled source audio-frequency magnetotellurics (CSAMT)



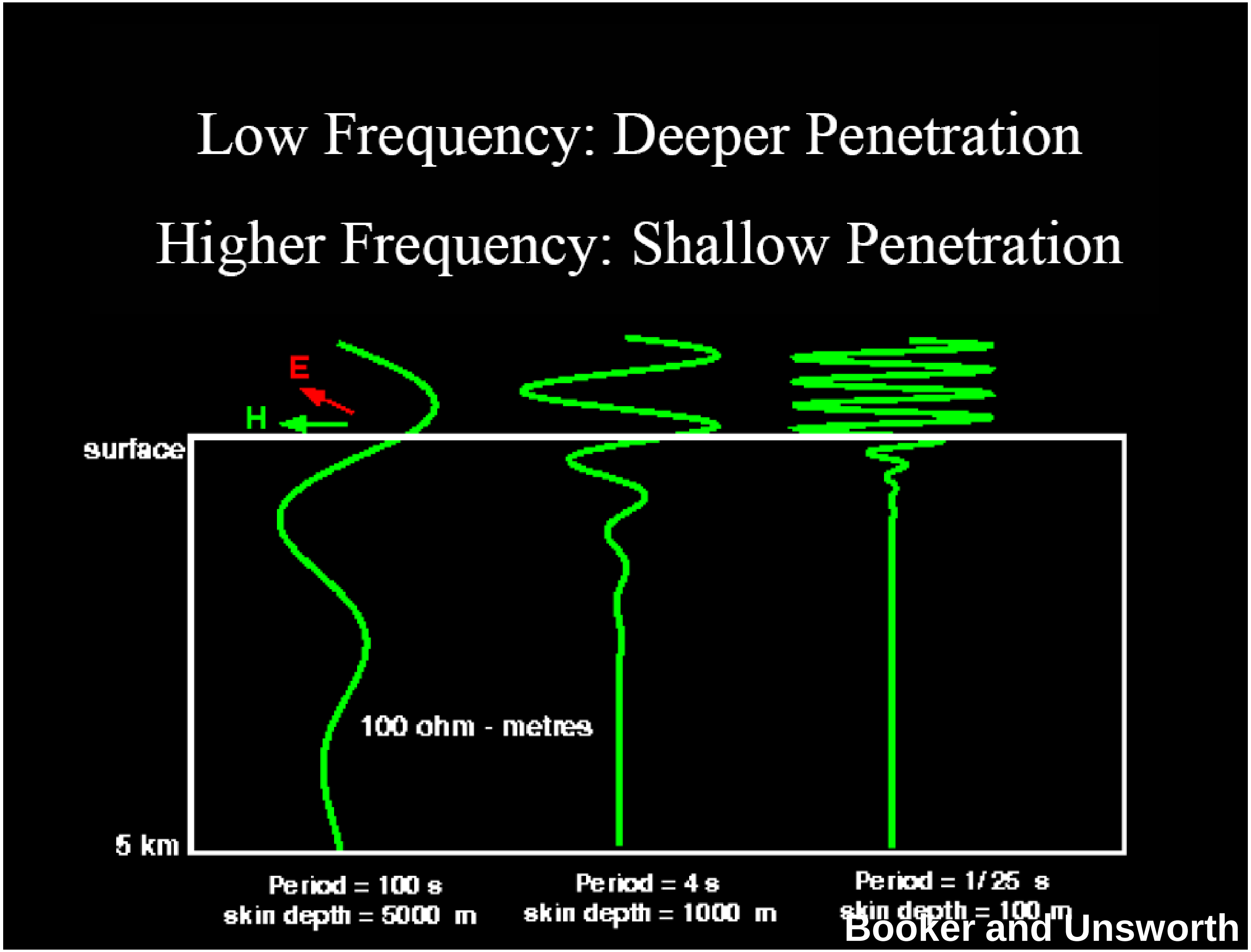


Location – Northeast of Weiser, Idaho

Survey Layout



Multi-Frequency Data



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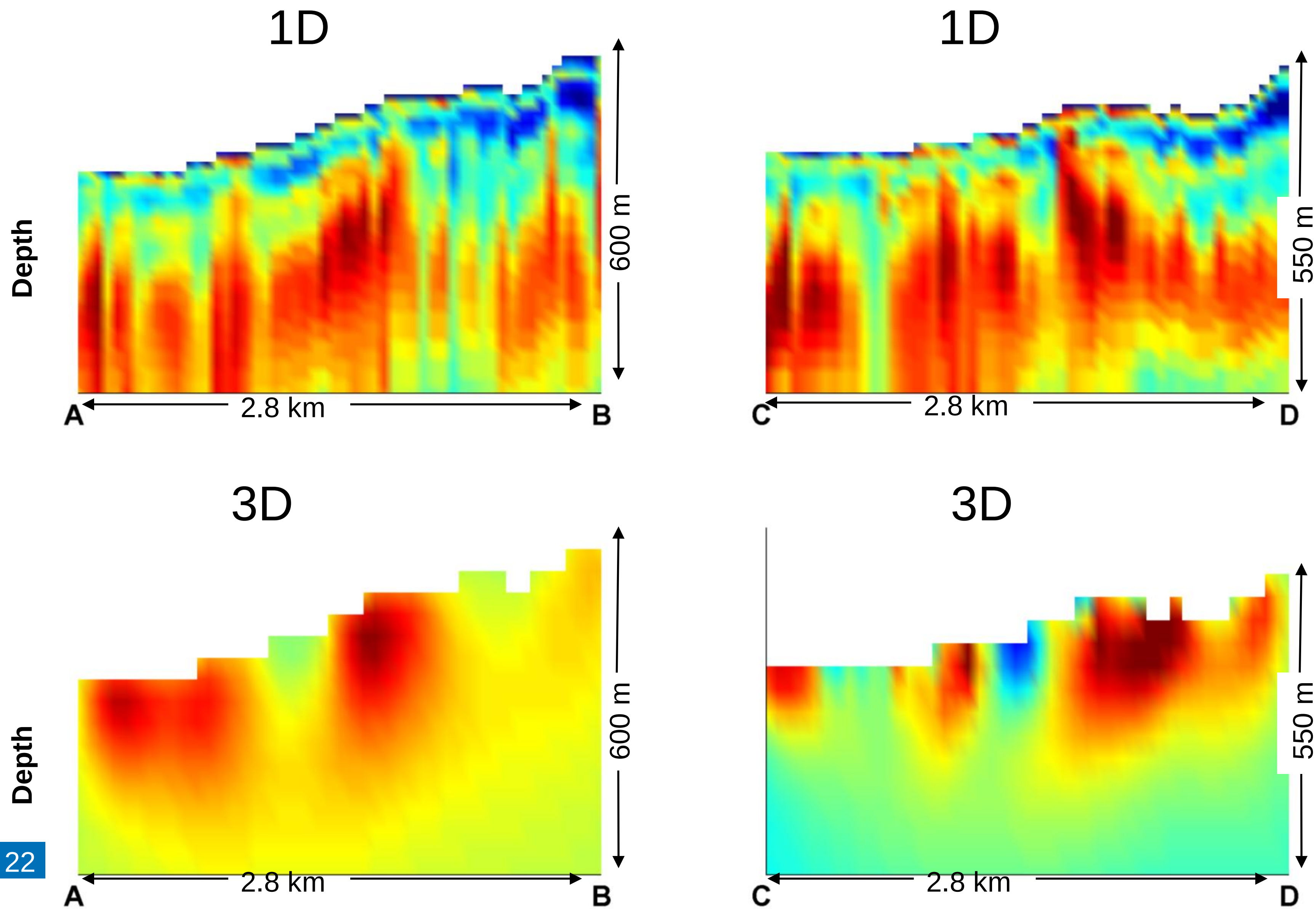
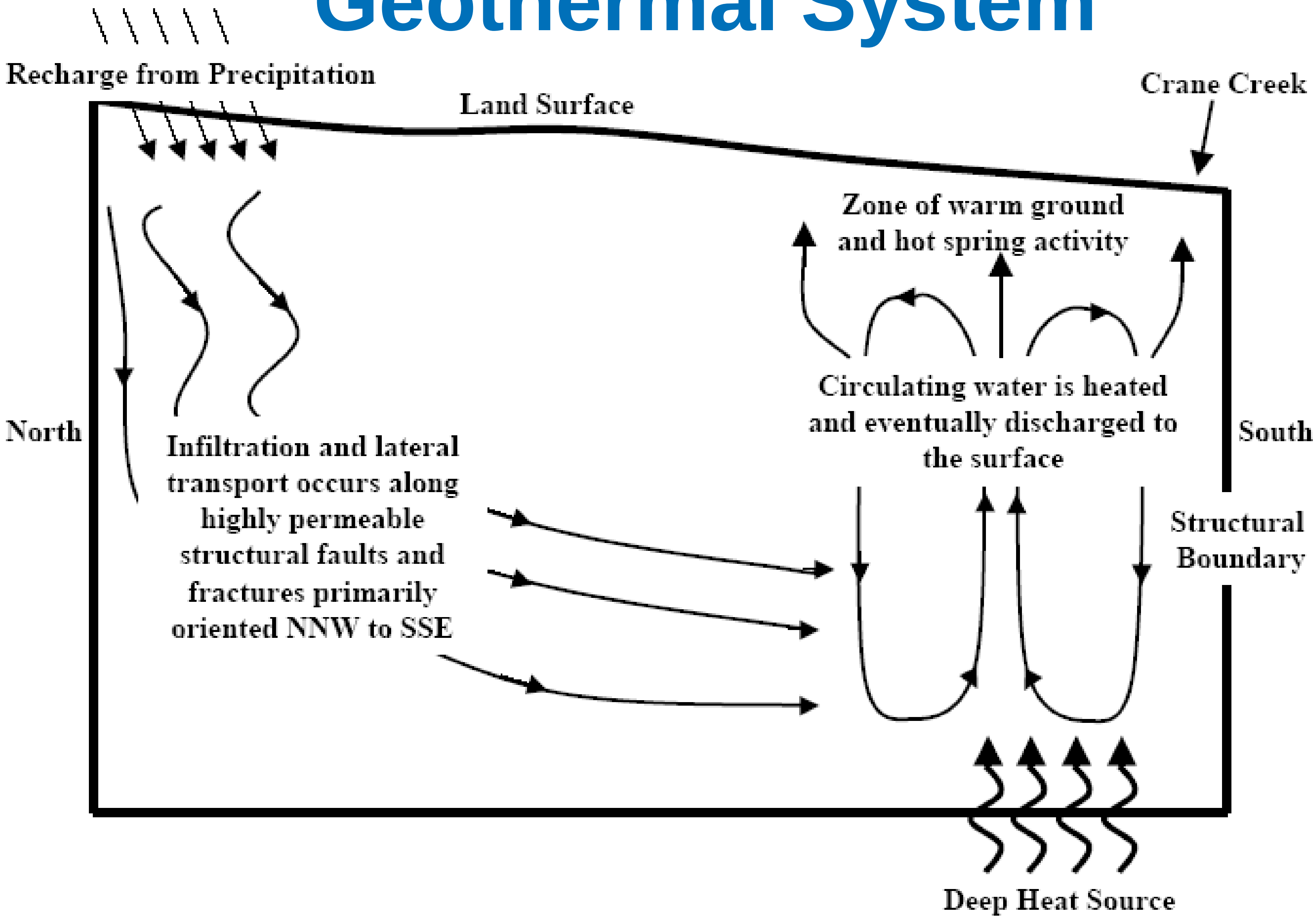
Model Slices



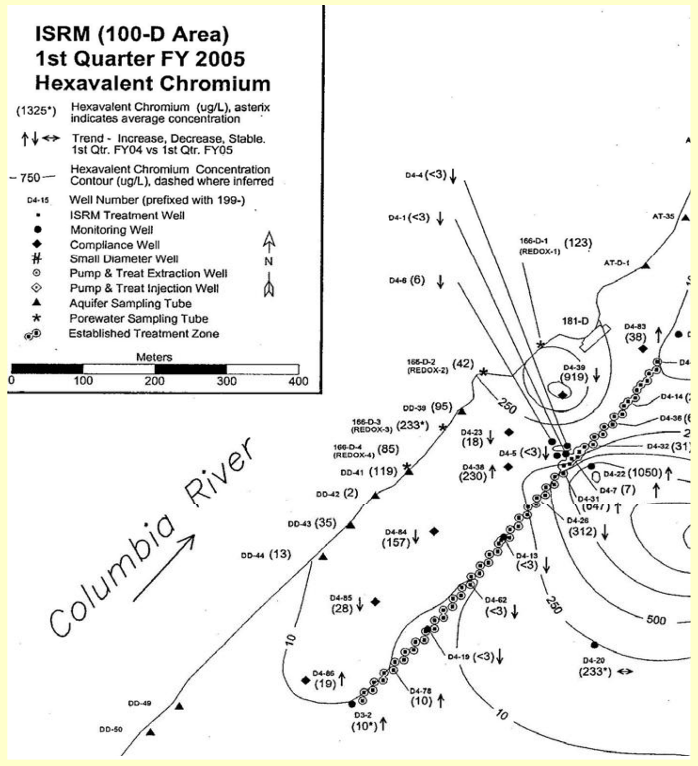
Conceptual Model of Geothermal System



Multiple Methods

Goal – Verify ZVI emplacement in subsurface redox manipulation barrier

Methods – Electrical resistivity, Induced polarization, Borehole logging



Location – DOE Hanford Site, Washington State

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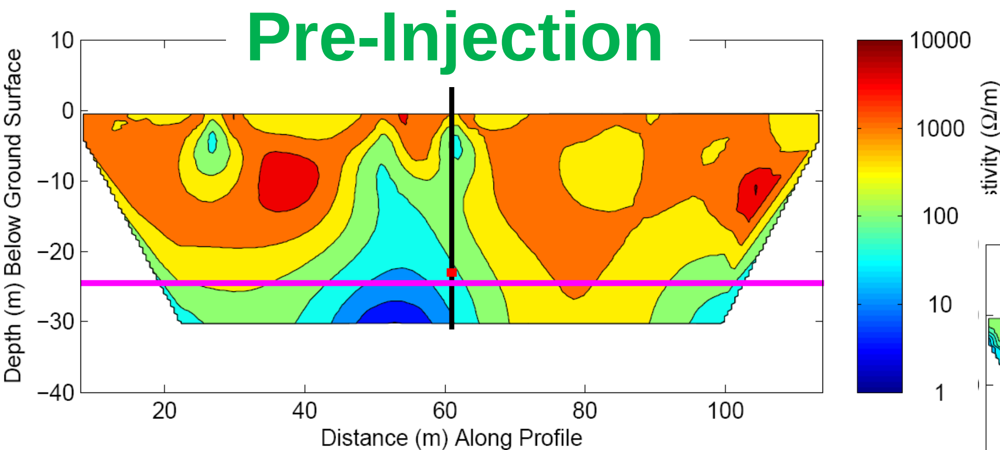
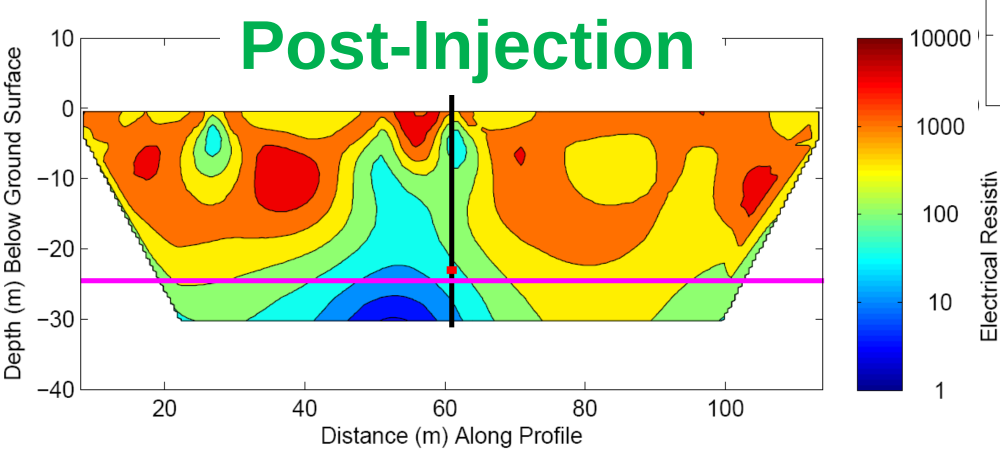
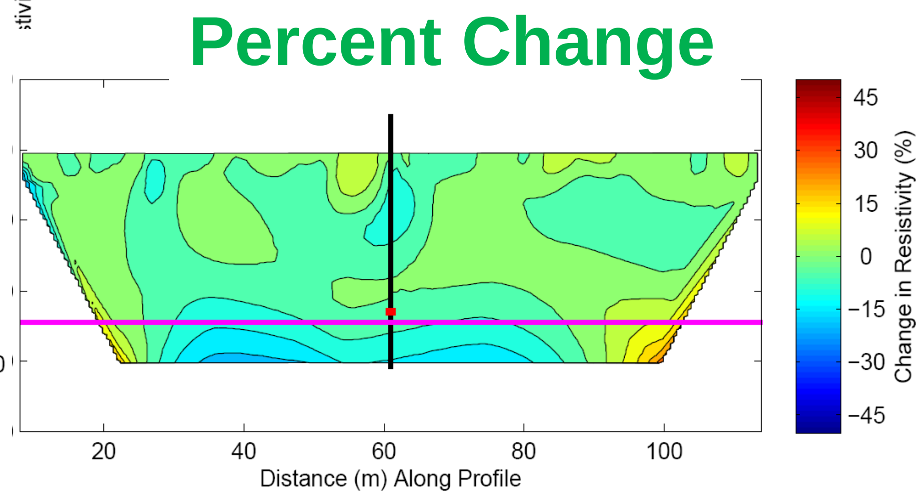
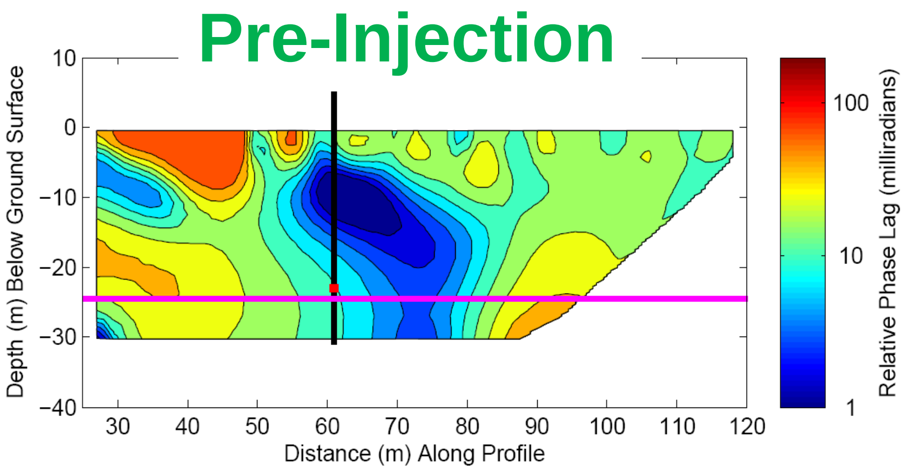
Resistivity Models

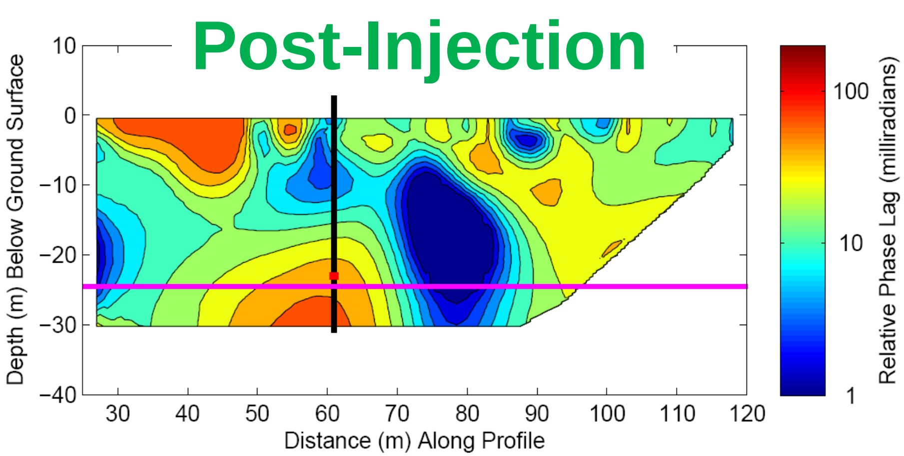


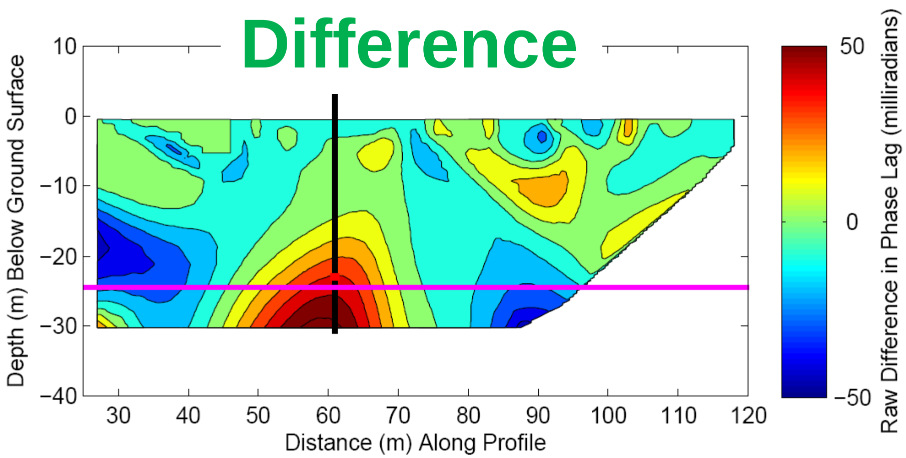




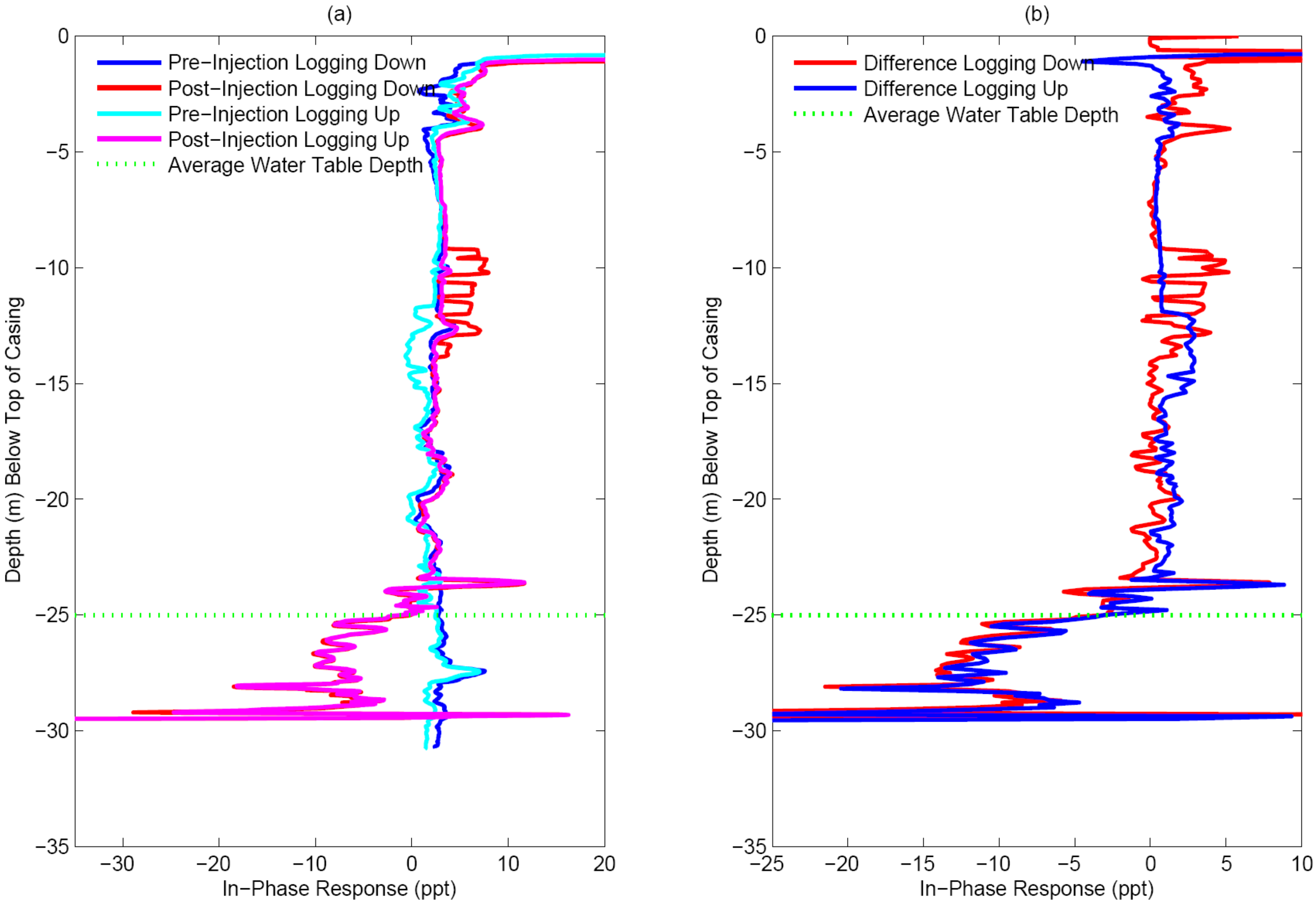
Chargeability (IP) Models







Borehole EM



(a)
Pre−Injection Logging Down
Post−Injection Logging Down
Pre−Injection Logging Up
Post−Injection Logging Up
Average Water Table Depth
Depth (m) Below Top of Casing
In−Phase Response (ppt)
0
−5
−10
−15
−20
−25
−30
−35
−30
−20
−10
0
10
20
(b)
Difference Logging Down
Difference Logging Up
Average Water Table Depth
Depth (m) Below Top of Casing
In−Phase Response (ppt)
0
−5
−10
−15
−20
−25
−30
−35
−25
−20
−15
−10
−5
0
5
10

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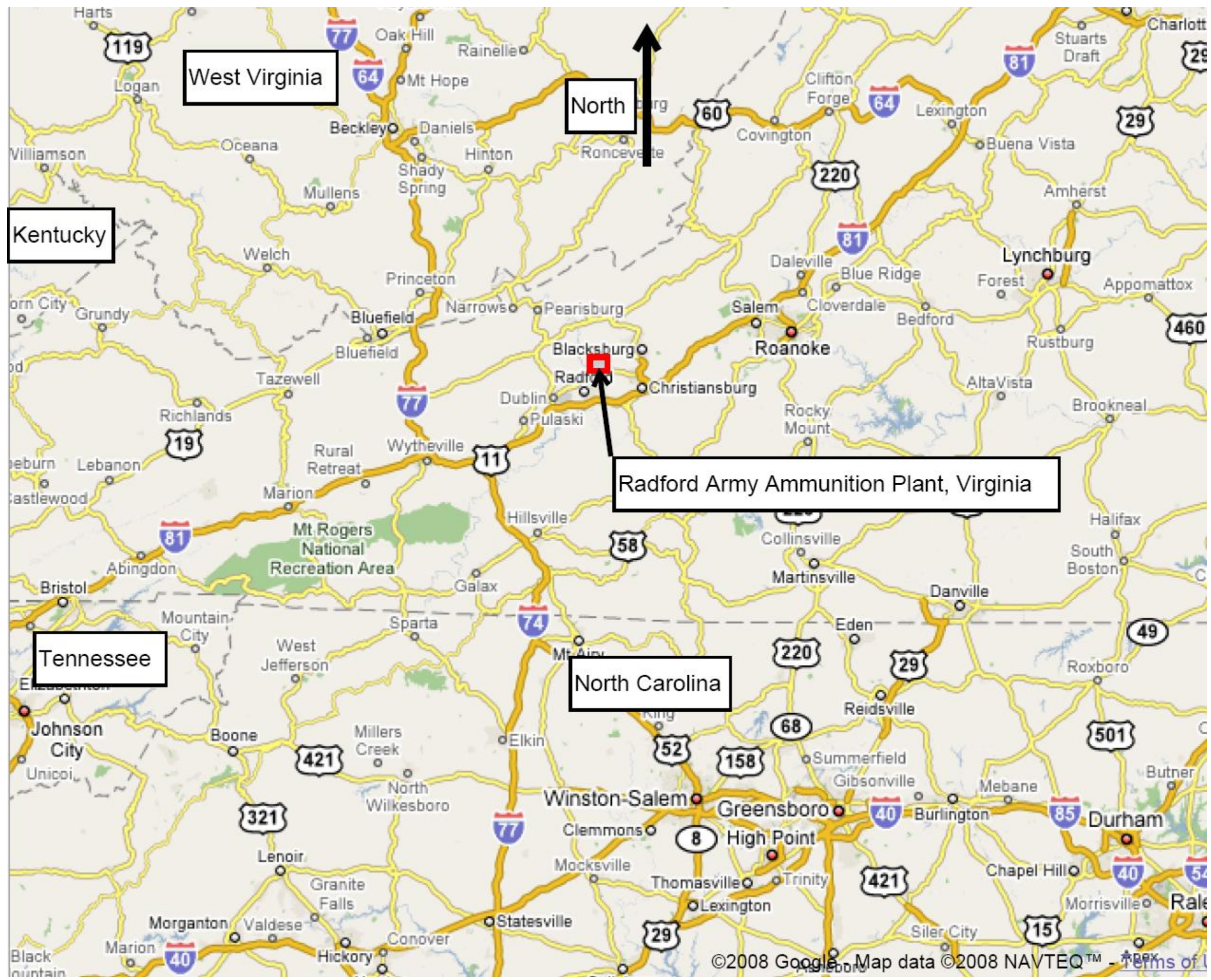
Seismic Refraction

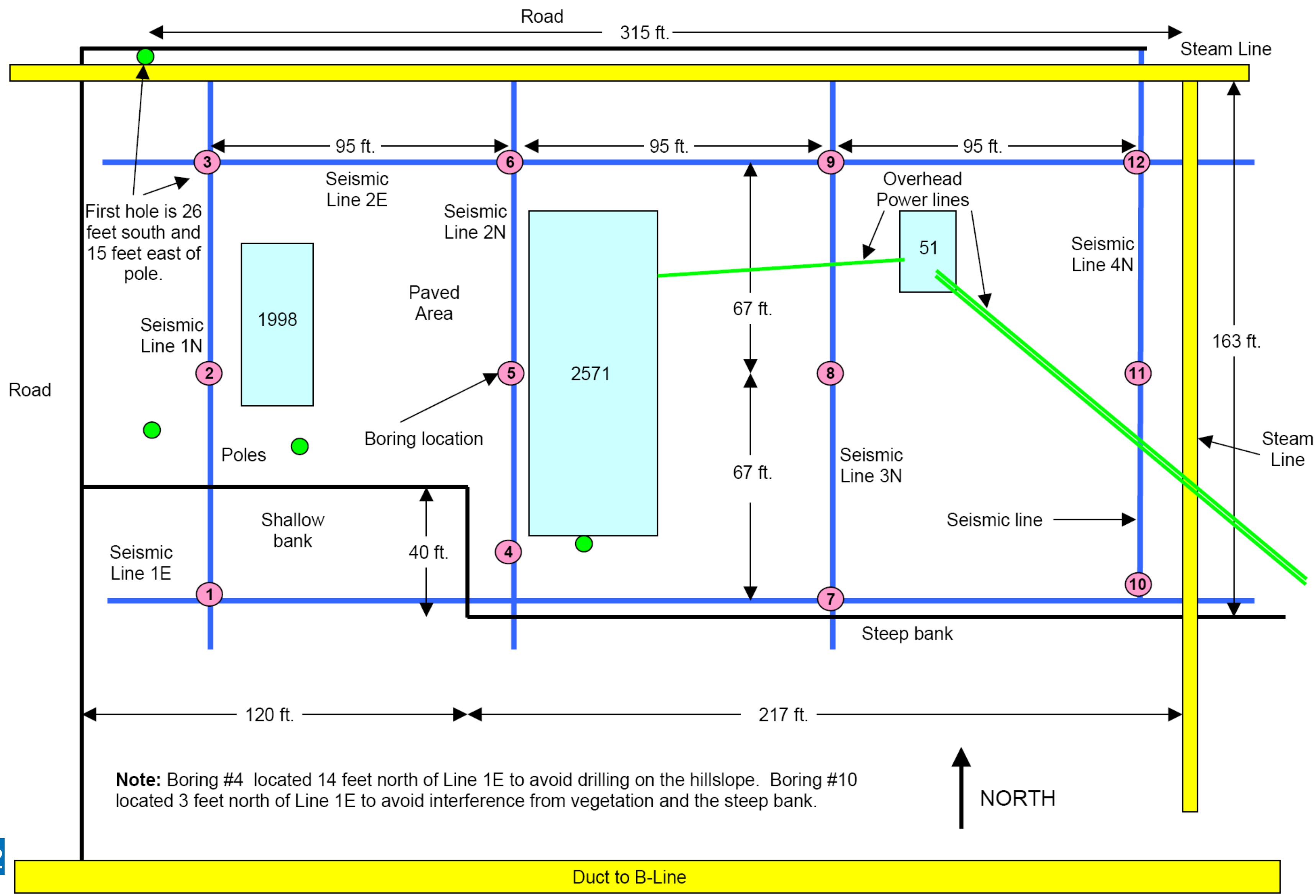
Goal – Characterize a construction site and identify possible karst sinkhole features or other hazards

Method – Seismic Refraction

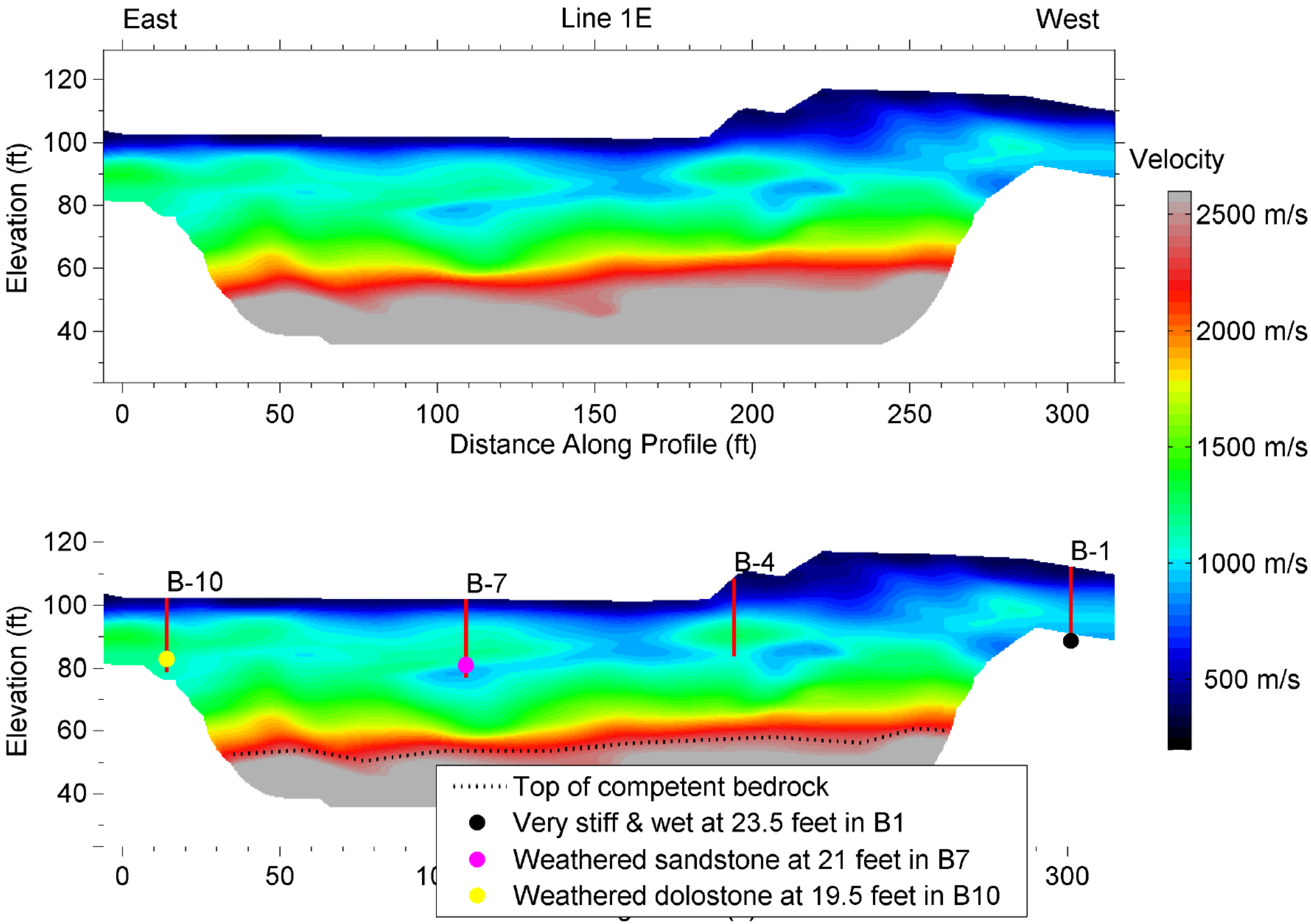
Location – Radford Army Ammunition Plant, Virginia



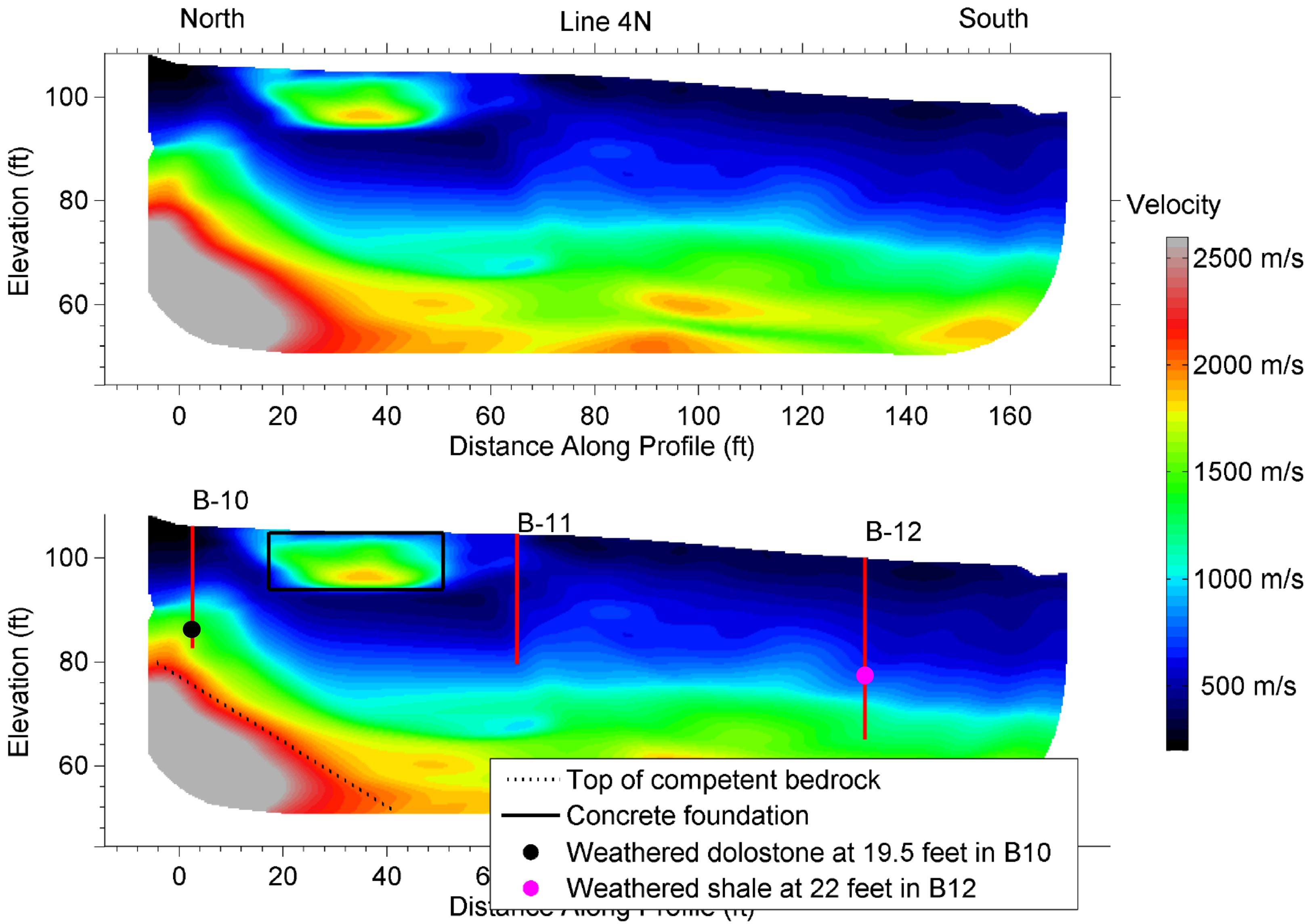
Site Plan


Road
315 ft.
Steam Line
95 ft.
95 ft.
95 ft.
3
6
9
12
Seismic Line 2E
Overhead Power lines
First hole is 26 feet south and 15 feet east of pole.
Seismic Line 2N
51
Seismic Line 4N
1998
Paved Area
67 ft.
163 ft.
Seismic Line 1N
2
5
2571
8
11
Road
Boring location
Poles
Seismic Line 3N
67 ft.
Steam Line
Shallow bank
Seismic line
40 ft.
4
Seismic Line 1E
1
7
10
Steep bank
120 ft.
217 ft.
Note: Boring #4 located 14 feet north of Line 1E to avoid drilling on the hillslope. Boring #10 located 3 feet north of Line 1E to avoid interference from vegetation and the steep bank.
NORTH
Duct to B-Line

Velocity Model



Velocity Model

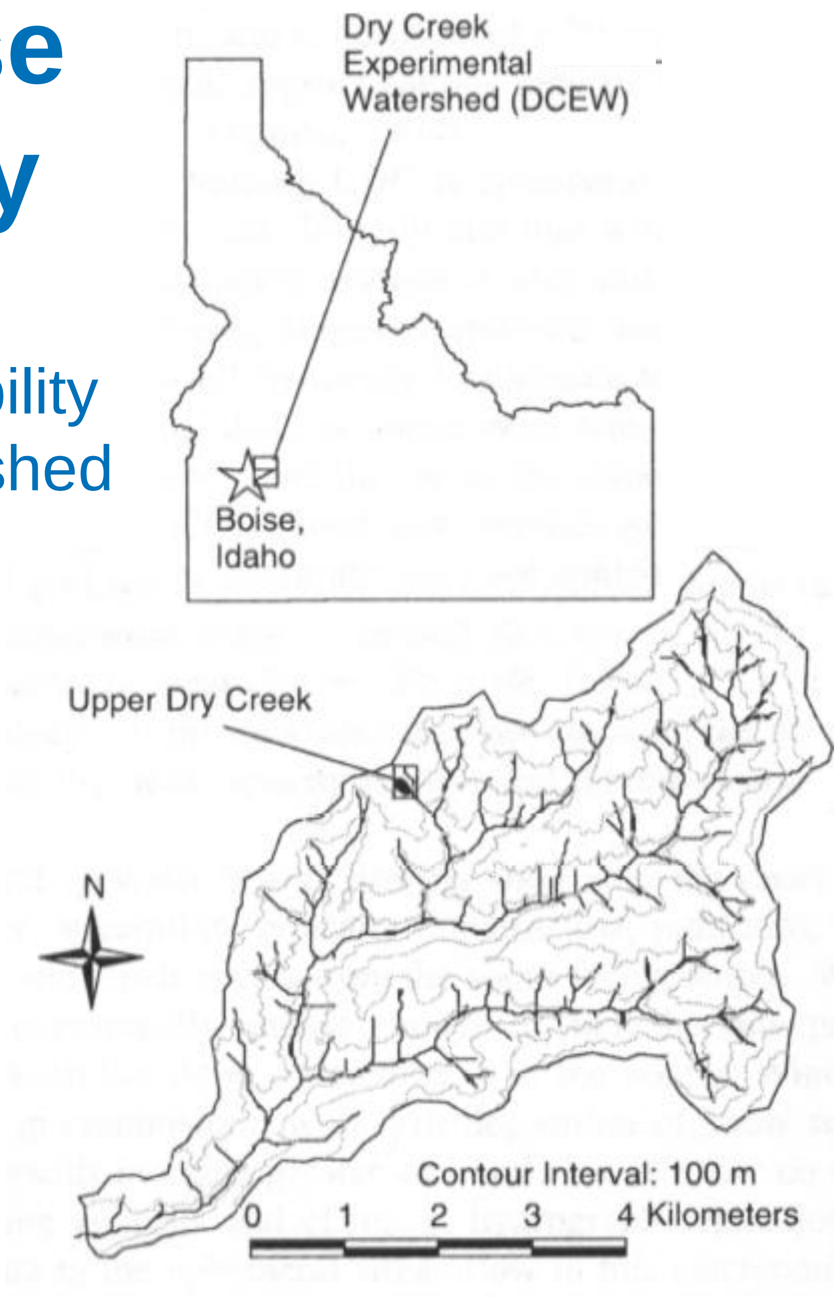


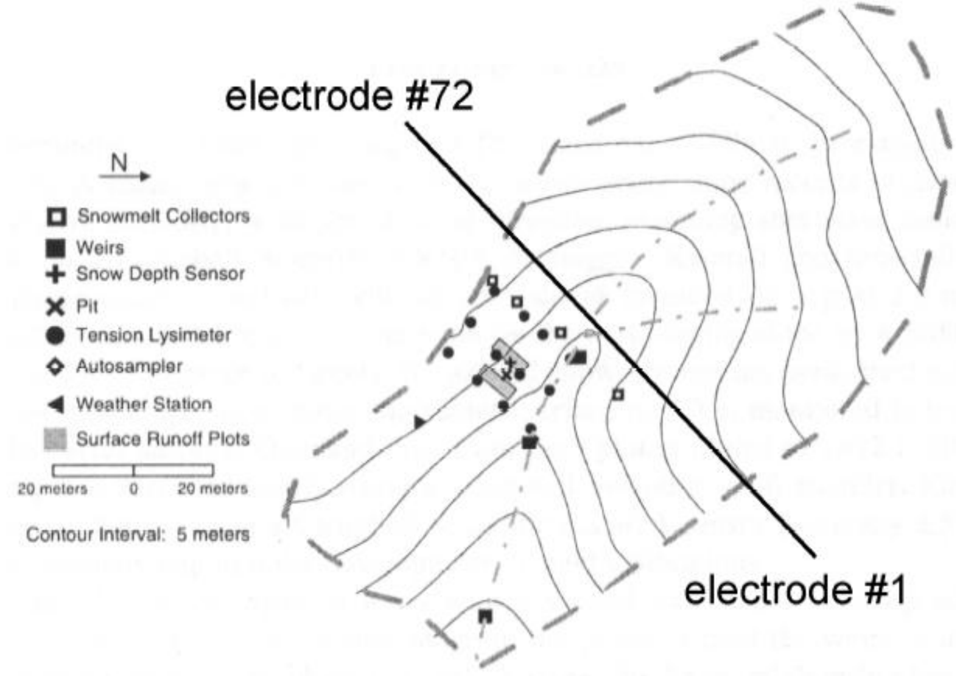
Time Lapse Resistivity

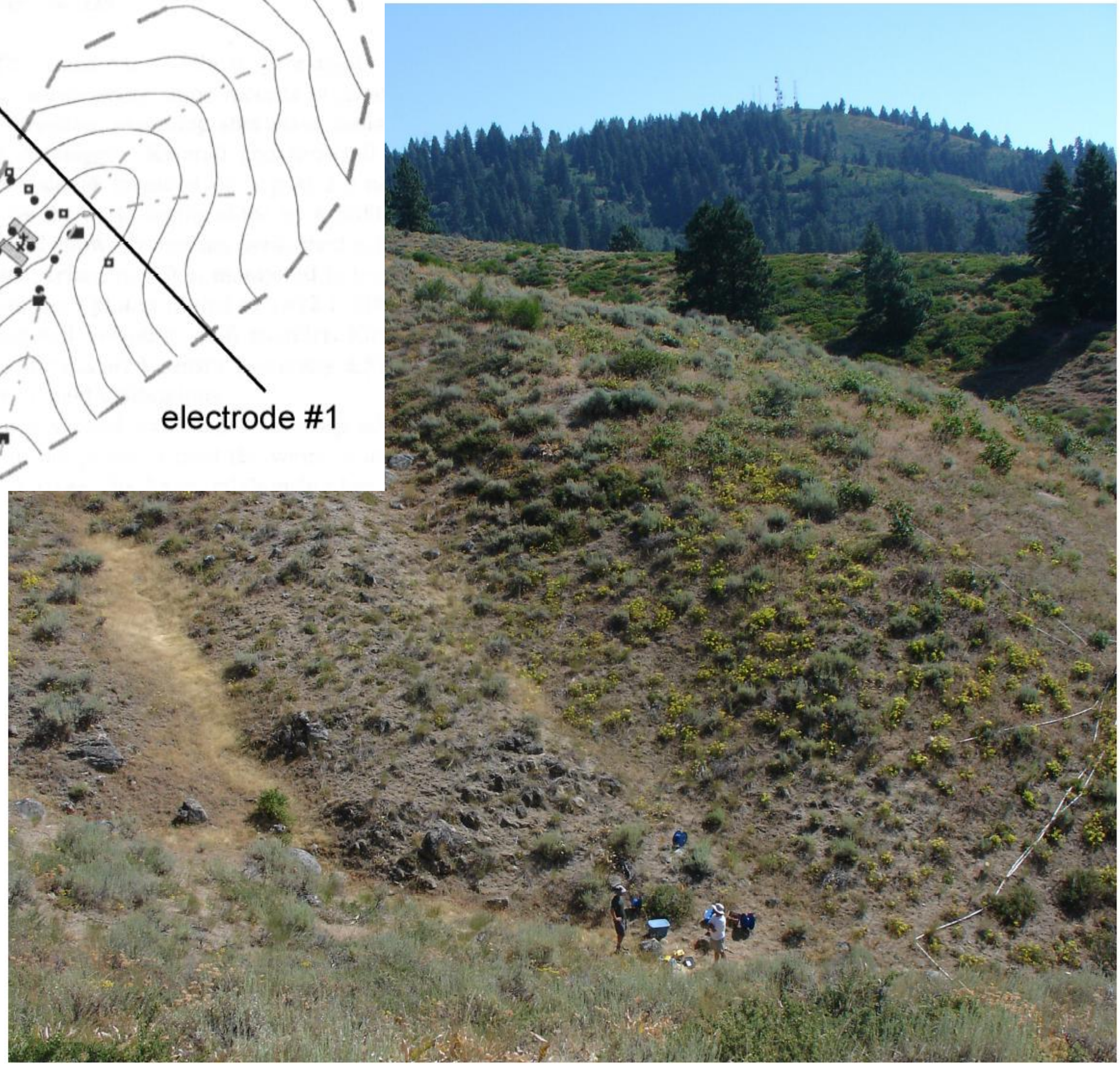
Goal – Determine seasonal variability in water storage for a small watershed

Method – Time lapse resistivity

Location – North of Boise, Idaho

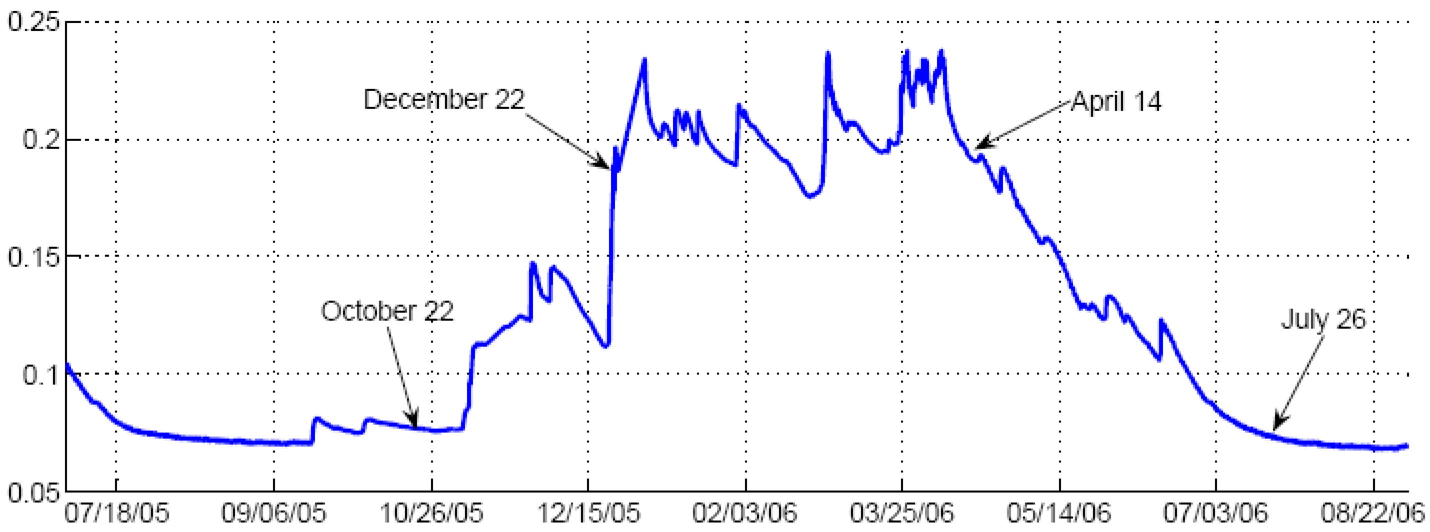






Survey Layout

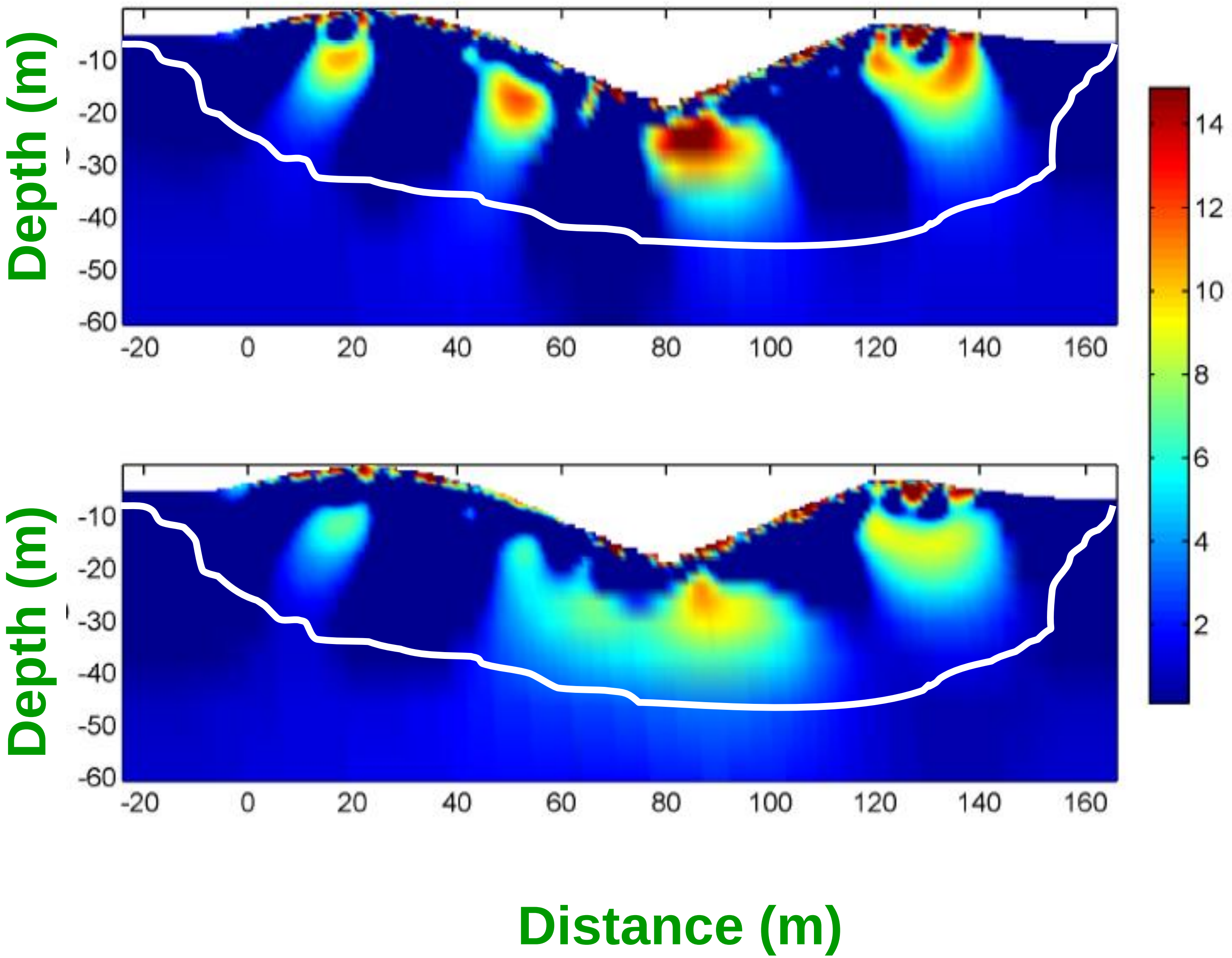
Survey Timing



Soil moisture sensors buried 5, 15, 30, 45, and 60 cm deep

Data acquisition was timed to capture two dry periods and two wet periods

Saturation Changes



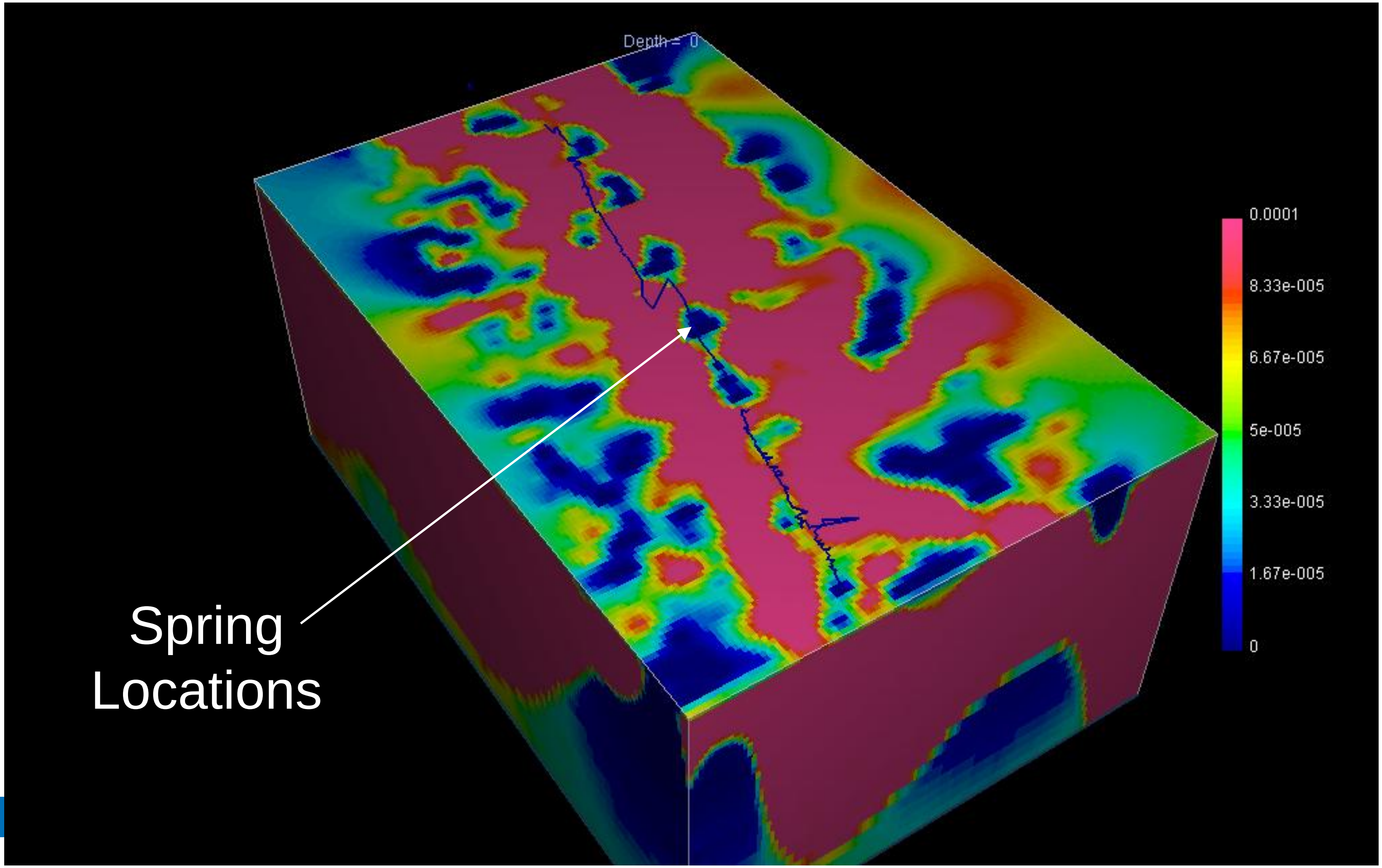
Magnetics

Goal – Characterize a geothermal system

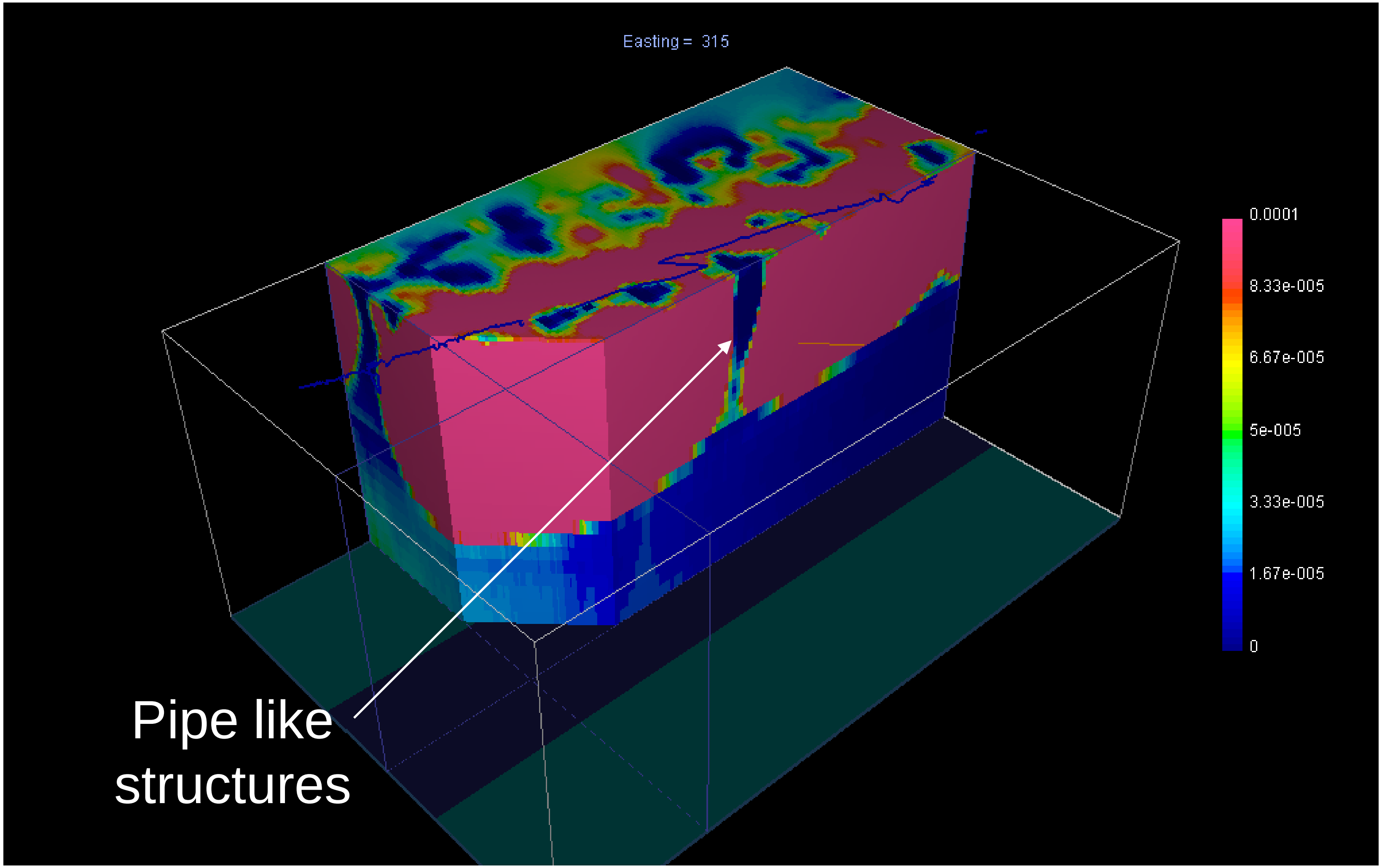
Method – Magnetics

Location – Alvord Desert,
Eastern Oregon

Susceptibility Model



Slice Through Model



Questions?

Contact Info:
Miller.Carlyle@epa.gov
(580)-436-8950

Near Surface EM Tools

System	Description	Horizontal Resolution	Vertical Resolution	Frequency/ Time Domain/ Static
EM31	Vertical Loop/ Horizontal Loop. Coil separation 3.7m	Few meters	Between 1-6m.	Frequency domain. Operates at 9.8 KHz
EM 34-3	Vertical Loop/ Horizontal Loop. Coil separation 10,20,40 m	Tens of meters	Between 4-60m.	Frequency domain. 0.4,1.6,6.4 kHz.
EM 61	Coincident Loop	1m	3-5m	Time Domain
Protem	Loop TX: 5m-100m, RX: 60cm	Wider than TX Loop	Few to hundreds of meters	Time domain: with time gates 6microsec-32ms
Syscal	Multi-Channel Resistivity system	Depends on electrode spacing	Cm to 100s of meters	DC potentials measured
OhmMapper	Capacitively coupled system at 17 kHz	Depends on electrode spacing	Cm to 100s of meters	Electric Field measured